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J952-20

Impacts of Technology on U.S. Cropland and Rangeland Productivity

Volume II—Background Papers

Part C

Paper No.
14. Description and Evaluation of Pesticidal Effects on the Productivity of the Croplands and Rangelands of the United States
15. New Roots for American Agriculture
16. An Overview of Major Legal and Policy Issues Related to the Impact of Technology on the Productivity of the Land
17. Relationships Between Land Tenure and Soil Conservation
18. Data Base on Ground Water Quality and Availability: Effects on Productivity of U.S. Croplands and Rangelands

December 1982

CONGRESS OF THE UNITED STATES
Office of Technology Assessment
Washington, D.C. 20510

Preface

This volume contains papers written for OTA to assist in preparation of the report *Impacts of Technology on U.S. Cropland and Rangeland Productivity.* OTA does not endorse these papers. In several instances, the OTA report reaches somewhat different conclusions because of additional information which was obtained later. These papers, however, may prove valuable for readers needing more detailed or specific information than could be accommodated in the final assessment report, and are being made available for such purposes.

Background Paper No. 14

DESCRIPTION AND EVALUATION OF PESTICIDAL EFFECTS ON THE PRODUCTIVITY OF THE CROPLANDS AND RANGELANDS OF THE UNITED STATES

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September 1980

Office of Technology Assessment
U.S. Congress

This background paper was prepared for the assessment "Impacts of Technology on U.S. Cropland and Rangeland Productivity." The views expressed are those of the author(s) and not necessarily those of OTA.

CONTENTS

- Contents i
- Figures ii
- Tables iii
- Introduction 1
- Data Base Deficiencies and Recommendations 9
- Agricultural Productivity and Pesticide Use 13
- Monitoring Data and Programs 26
  - Who is Performing Monitoring Programs 26
  - Kinds of Measurements Being Made 28
- Environmental Distribution and Fate of Pesticides 32
  - Pesticide Transport in the Environment 32
    - Atmospheric transport 32
    - Subsurface drainage 33
    - Surface runoff and sediment transport 33
  - Persistence and Degradation 34
    - Adsorption 36
    - Chemical degradation 36
    - Photochemical degradation 36
    - Microbial degradation 37
    - Uptake by higher organisms 37
    - Extent of environmental contamination 38
- Causes and Consequences of Ecosystem Changes Related to Pesticides 39
  - Pesticides and Soil Microorganism 39
    - Effects on nitrification and ammonification 39
      - Herbicides 40
      - Insecticides 40
      - Fungicides 41
    - Effects on nitrogen fixation 41
      - Symbiotic nitrogen fixation 41
      - Non-symbiotic nitrogen fixation 42
    - Effects on organic matter decomposition 42
  - Pesticdes and Soil Invertebrates 42
  - Pesticides and Aquatic Systems 43
    - Pesticides and aquatic microorganisms and phytoplankton 43
    - Pesticides and aquatic invertebrates 43
    - Pesticides and fish 44
  - Pesticides and Beneficial Insects 44
- Bibliography 45

FIGURES

Number		Page
1	Summary of types of pesticides and their modes of action......	2
2	Production of synthetic organic pesticides in the United States, 1962-1978....................................	4
3	Total domestic use and farmers' use of pesticides (active ingredients) in the United States............................	5
4	Trend of farmers' usage of synthetic organic insecticide in the United States..	6
5	Amount of mercury used in pesticide for agriculture (for crop, livestock, noncrop, and nonlivestock....................	7
6	Major uses of land in the United States in 1974...............	14
7	Farm production regions in the United States..................	15
8	Persistence of pesticides in soils...........................	30
9	Dissipation and degradation of pesticies in the environment...	35

TABLES

Number		Page
1	Distribution of on-farm use of pesticides between 1964 and 1976	3
2	Some typical losses in unprotected crops caused by insects, disease, and weeds	17
3	Percentage of crop area treated with pesticides (active ingredients) and percentage of pesticides used on crops in the United States, 1976	18
4	Percentage of area treated and pesticides used on major crops, hay, and pasture and rangeland, by region, in the United States	19
5	Acreages, yields, production and average prices of grain corn and soybeans, 1964-1979	21
6	Some major advantages and disadvantages of herbicides and insecticides	24

Background Paper No. 14

Description and Evaluation of Pesticidal Effects on the Productivity of the Croplands and Rangelands of the United States

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INTRODUCTION

Pesticides are chemicals used primarily to combat pests which affect food and fiber production or cause a public health hazard. They are broadly classified on the basis of the kinds of pests they control, namely, insecticides, herbicides, fungicides, nematicides, rodenticides and miticides. However, chemicals used for defoliation, desiccation, soil fumigation, and plant growth regulation also are classified as pesticides (89).

Contrary to popular opinion, pesticides are not a recent development in agriculture. Even in classical times, sulfur was used for mildew control on grapes, as witnessed by the Greek poet Homer. Sulfur lime was commonly used for pest control in the 18th century, as were soap solutions, turpentine, petroleum and fish oil, soot, whitewash, lye, brine, wood ash, vinegar and such plant products as herbs, pepper, and extracts of bitter aloes, tobacco, hellebore (buttercup family) and quassia, a drug obtained from the heartwood of tropical trees of the ailanthus family (16).

Scientific pest control dates from the introduction of Paris green—a copper-arsenic compound used to control the Colorado potato beetle—in 1867. Paris green, lead and calcium arsenates, carbon disulfide, hydrogen cyanide and the natural plant insecticides—nicotine, pyrethrum and rotenone—were the most frequently used pesticides at the beginning of the 20th century, since these materials were reliable and outperformed most of the "nostrums" previously used. However, prior to World War II, apart from the occasional use of methyl bromide, ethylene dichloride or ethylene oxide as soil fumigants or of carbon disulfide and hydrocyanic acid as fumigants for stored grain, and of some nitrophenols used to kill mites and aphids, no man-made organic (carbon-containing) chemicals were used in pest control.

Most pesticides presently in use are organic chemicals. Some are man-made and some are of natural origin. Many contain chlorine, nitrogen, sulfur or phosphorus which serve to determine the toxicological impacts of the compounds. To show the diversity in the modes of action of various pesticidal types, a chart from Corbett (32) is reproduced as Figure 1. From these brief descriptions it can be seen that pest control is achieved by a broad spectrum of disruptive effects on the target organisms and that pesticides are "built" or "tailor-made" to attack specific functions of the pest.

INSECTICIDES

Organophosphorus and carbamate compounds Nicotine, cartap DDT and related compounds, pyrethroids Cyclodienes and other organochlorine compounds	disrupt →	Nervous coordination
Polyoxin D Thiolcarbamates, triarimol Petroleum oils	disrupt →	Structural organization

HERBICIDES and FUNGICIDES

Bipyridylium compounds	disrupt →	Structural organization and energy supply
Antimonials and mercurials Many arsenical, inorganic copper compounds, hydroxyquinolines, pyridinethione, dialkyldithiocarbamates Dinitrophenols, hydroxybenzonitriles Ureas, triazines, uracils, some *N*-phenylcarbamates	disrupt →	Energy supply
Aminotriazoles *N*-Phenylcarbamates, dinitroanilines Several antibiotics, benzimidazoles Phenoxyalkanoic and benzoic acids	disrupt →	Growth and reproduction

Figure 1. Summary of types of pesticides and their modes of action; after Corbett, (32). Pesticides appearing on the same line have similar specific physiological effects.

Production and usage of organic pesticides in the United States have increased rapidly since the introduction of DDT in the mid-1940's (Figure 2). Since 1962, pesticide production (including exports) has more than doubled from approximately 680 million pounds to present levels of approximately 1,420 million pounds (5,131,152,153,156). Production of insecticides and fungicides have remained relatively constant between 1962 and 1980, but massive increases have occurred in the use of weed control chemicals (110 million pounds in 1962, 660 million pounds in 1978). The United States consumption of pesticides now represents only 32.7% of world use and this percentage is gradually decreasing (5,42,89). Approximately 36,000 pesticidal labels are now registered with the U.S. Environmental Protection Agency although in practice only a few active ingredients and formulations are used extensively. Estimates indicate that the agricultural sector is the major user of pesticides; where amounts used are increasing at a more rapid rate than consumption by such other users as homeowners, industry, institutions and government (152).

The amount (Figure 3) and distribution (Table 1) of farm use of pesticides from 1964 to 1976 (latest available statistics) as a portion of total United States pesticide usage reveals some changes with time (152,153). Most (88%) of the insecticides produced in 1964 were for on-farm use; less than 60% was used for agricultural purposes in 1976. Herbicide usage on the farm continues to increase but fungicides (60 to 75%) are used largely for purposes other than agriculture.

Table 1. Distribution of on-farm use of pesticides between 1964 and 1976

Year	On-farm use (% of total use) of pesticides* in the United States			
	All	Herbicides	Insecticides	Fungicides
1964	68	66	88	32
1966	52	55	59	26
1971	59	70	63	27
1976	65	74	59	39

*Herbicides include plant hormones, defoliants and desiccants; insecticides include miticides and fumigants.

During the past decade a significant shift occurred in the agricultural use of insecticides with an increase in the use of organophosphorus and carbamate compounds and a decline in the use of organochlorine compounds (Figure 4). The decline in organochlorine insecticides will continue as a result of government restrictions on their use due to adverse environmental impacts. The rapid decrease in the use of the "hard" organochlorine pesticides is evident and if data for 1980 were available even more dramatic changes in the distribution of these types of compounds would be revealed. Restrictions have been placed on arsenic- and mercury-containing fungicides, and data for mercury compounds are shown in Figure 5; well-documented statistics on arsenic compounds are difficult to find.

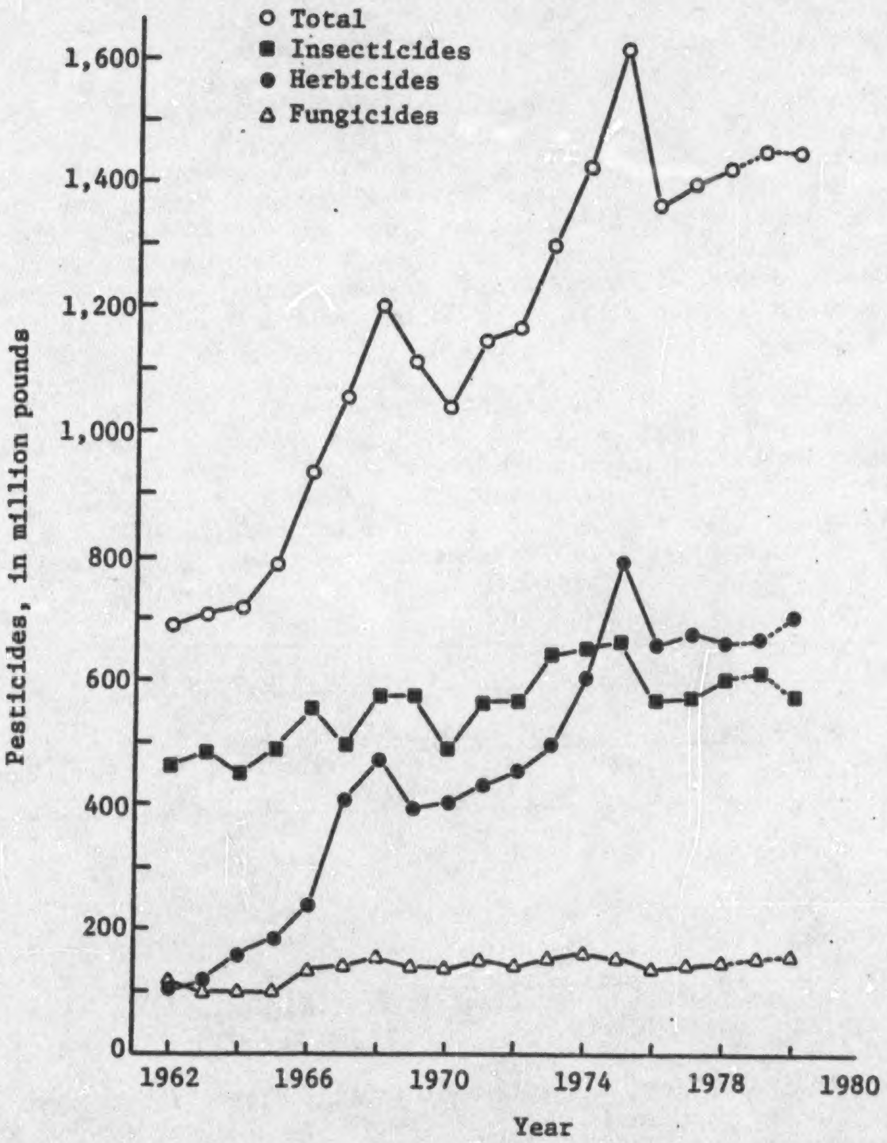

Figure 2. Production of synthetic organic pesticides in the United States, 1962-1978. Dashed lines are estimates. Data from USDA 1964-1978; projected in 1979 and 1980 (152, 153,156).

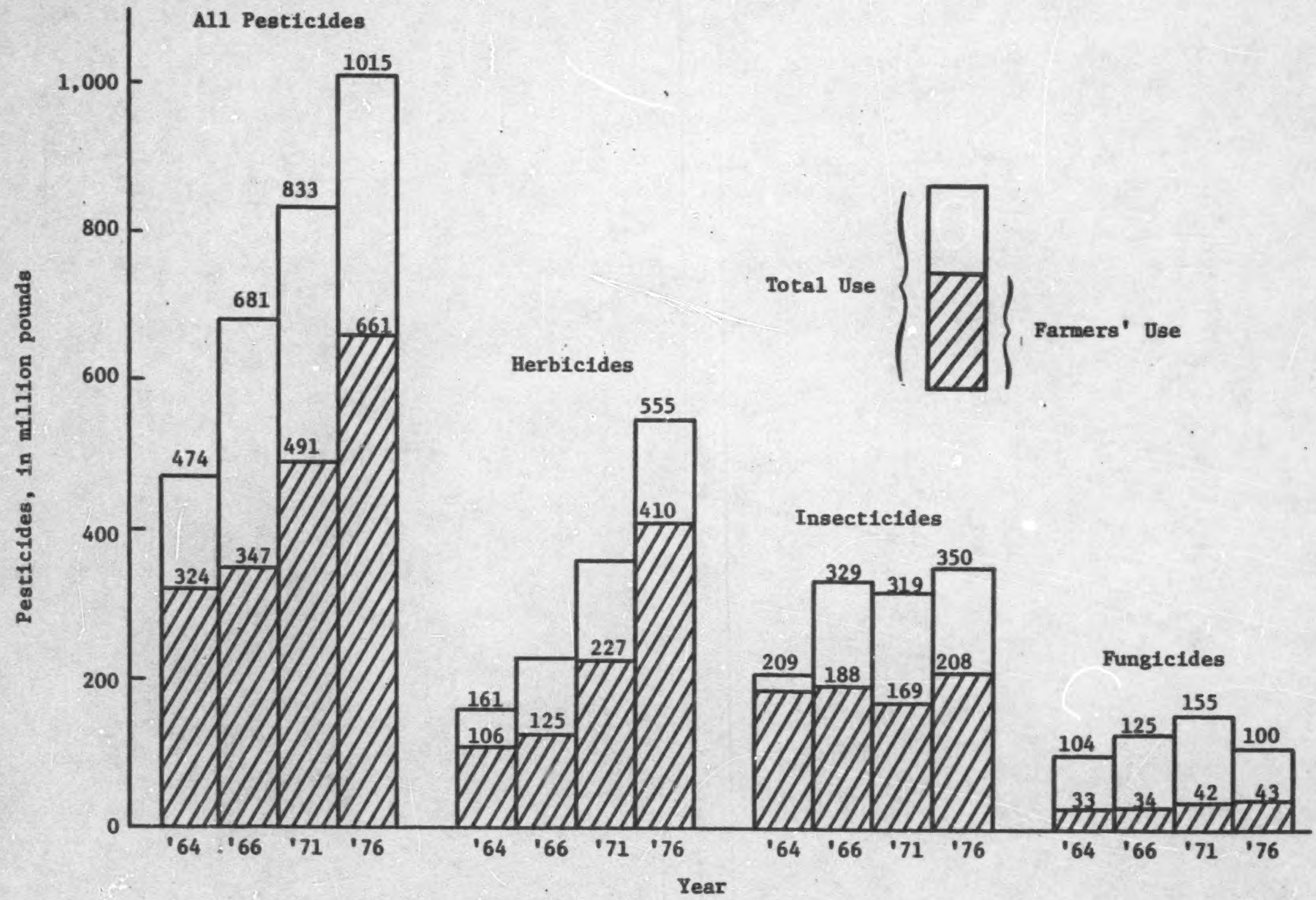

Figure 3. Total domestic use and farmers' use of pesticides (active ingredients) in the United States. Herbicides include plant growth regulators, defoliants, and desiccants; insecticides include fumigants, miticides, rodenticides and repellants. Sulfur and petroleum not included (152).

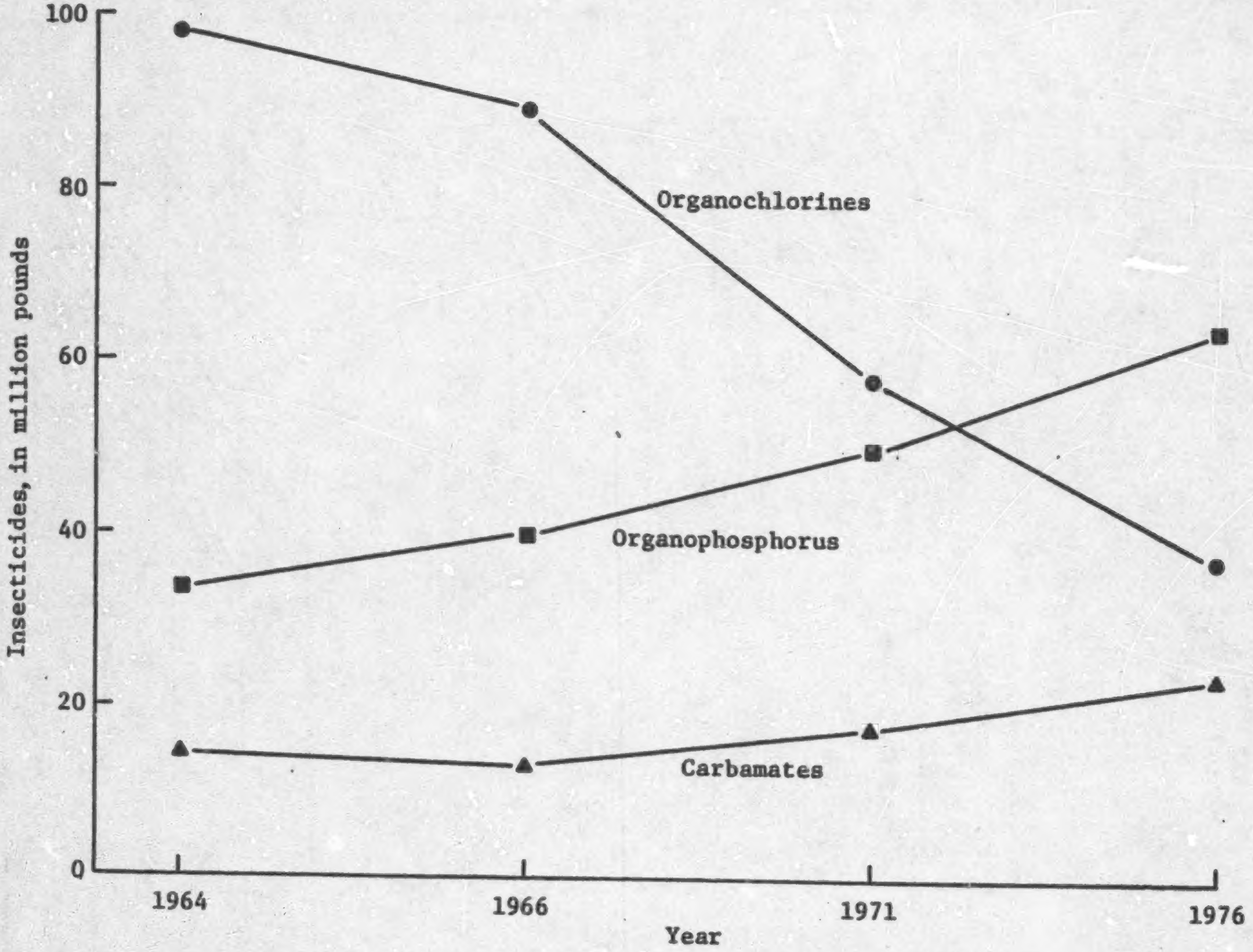

Figure 4. Trend of farmers' usage of synthetic organic insecticides in the U.S. (152).

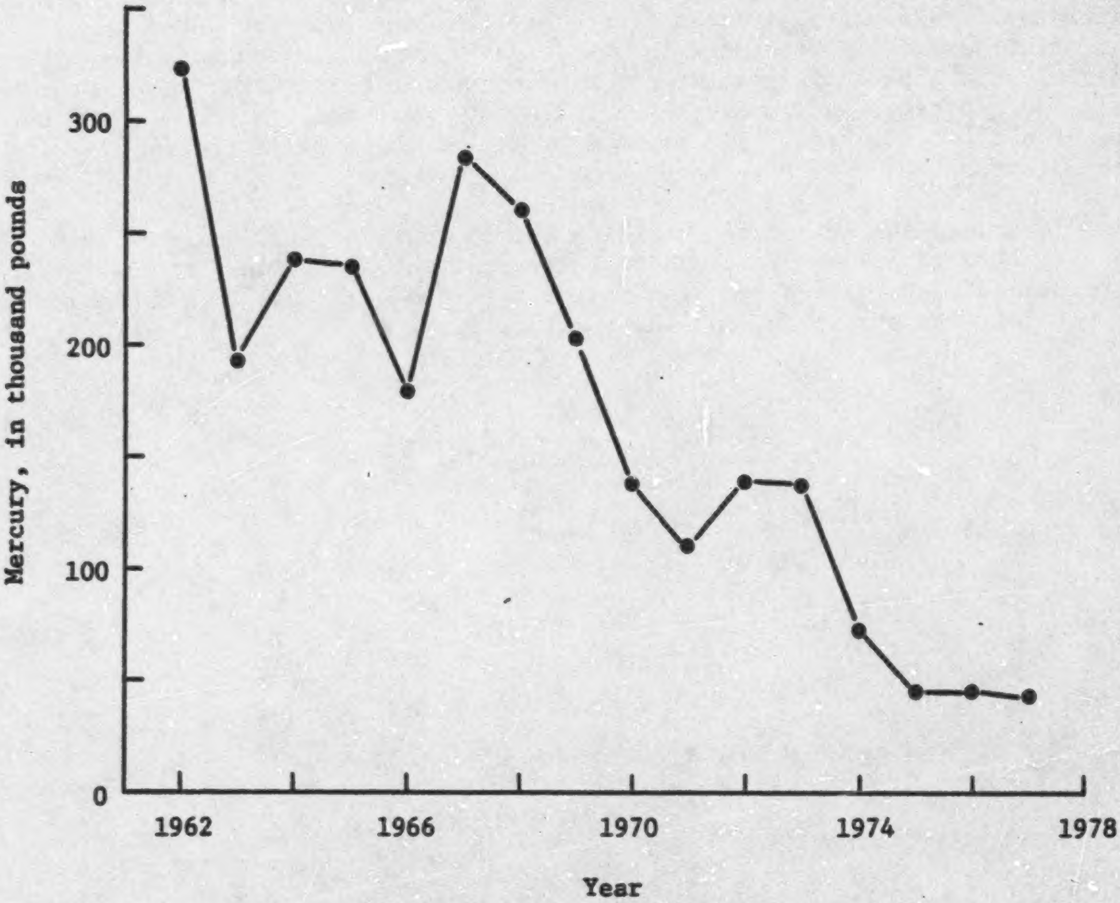

Figure 5. Amount of mercury used in pesticides for agriculture (for crop, livestock, noncrop, and nonlivestock) (153).

Mankind has benefited markedly from the use of pesticides, notably in terms of high production of food and fiber at relatively low cost and in improved public health (1,13,25,26,71,117,131,137). Experts predict that the demand for pesticides will continue to increase because of the lack of feasible alternative methods for control of most pests (1,5,23,25,26,30,61,71, 117,131,137,139, cf. 116). However, since the early 1960's when environmental awareness became acute, increasing concern has been expressed over the potential hazards associated with pesticide use. All agriculturally-applied pesticides are potential pollutants of food and drinking water and fish and wildlife habitats, but successful efforts have been made to produce and use new, "soft" (biodegradable) pesticides which minimize toxic residue accumulation.

To assess the impact of pesticide use on environmental quality, it is essential to stress the environmental transport of pesticides; their persistence, degradation and dissipation from the environment; and the hazards associated with pesticides and their metabolites.

DATA BASE DEFICIENCIES AND RECOMMENDATIONS

I. Meaningful integrated data on the productivity effects of agricultural usage of pesticides for individual crops, for type of pesticide and for different regions of the United States are extremely scarce (cf. 30,71). The value of crop improvements and cost:benefit ratios resulting from pesticide usage must be assessed and the assessment should be made for a series of time periods which reflect significant changes in pesticide formulation and technology. For example:

A. Pre-1950—when pesticide usage was relatively minimal (16).

B. 1951-1960--the period when the most detailed (150) and most quoted (117,123-128,131,137) USDA statistics on pest effects were available.

C. 1962-1978—an era characterized by enormous increases in herbicide usage with little shift in insecticide and fungicide applications (152,153).

D. 1973-present—a period of increased environmental awareness with a major shift in usage of chemicals from the "hard", residue-accumulating compounds to "soft", biodegradable compounds. The pest control effectiveness and impacts on productivity of this shift need evaluation.

The enormity of this task should not be underestimated because the overlapping impacts of several technology changes must be separated from pest control effects. The interrelated technologies include changes in 1. plant genetics (varieties), 2. fertilizer technology, 3. water use patterns, particularly irrigation, 4. land use and 5. tillage and cultivation practices. These effects from year to year are overlain by catastrophic or beneficial climatic and pest vectors, e.g., floods, frost, blights, drought, or advantageous weather patterns or predator-prey ratios.

An updated data base is not available to state what the implications for food and fibre production or the impacts on the agricultural economy would be if severe restrictions on pesticide usage were imposed. Because of year-to-year variability, decade averages should be sought as suggested in IA to ID. Furthermore, since catastrophic pest vectors are not predictable, the stability that pesticides lend to crop production and farm income should not be overlooked.

II. For control of sediment and other nonpoint sources of pollutants (28,29,58,59,98), a major effort is being made to direct technology toward no-till or minimum till agriculture in many regions of the United States (14,121,122). Concensus of opinion amongst agronomists, soil scientists, entomologists etc., is that this technology will increase disease incidence and weed growth necessitating increased pesticide usage to obviate decreased production. The environmental (decreased erosion and runoff) and energy-conserving benefits of these technologies must be assessed against the crop losses which might accrue if pest problems related to minimum till technologies are not countered.

III. Accurate assessments of crop losses on pasture and rangeland must be made. Present indications are that only about 1% of this type of land is treated with pesticides (152,153). Some germane questions include: A. are crop losses minimal in this type of agriculture; B. have cost:benefit analyses shown that improvements in rangeland productivity do not warrant the cost of pesticide application, or C. do the environmental and energy costs justify discouragememt of widespread use of pesticides on these lands?

IV. Assuming conditions of highly restrictive pesticide usage an evaluation must be made of:
   A. the extra land acreage which must be brought under cultivation and its availability,
   B. increased fuel consumptions and
   C. extended manpower demands

if agricultural productivity is to be maintained at present levels or if some incremental (perhaps 5, 10, 20%) increases in productivity must be achieved.

V. Better estimates must be established of pesticide production, need and demand and an evaluation made of the chemical industry's capacity to meet a major increased demand for agricultural use of pesticides as might arise from the widespread use of minimum tillage technologies. Also, the variety of pesticides available must be broadened to allow for pesticide rotation which would alleviate build-up of resistance in target organisms. The effects of costs associated with clearance of pesticides through the Food and Drug Administration and Environmental Protection Agency or pesticide development must be considered (102).

VI. With the shift toward the use of "soft" pesticides in agriculture it is becoming evident that the ecological impacts of pesticides are diminishing (9,20-22,23,91,93-96,130,135,144,171). However, small amounts of the "hard" residual pesticides continue to be found in the environment. This state of affairs is likely to continue for a protracted period of time; management strategies to alleviate the problem appear not to be available or likely to become available. The need for expensive, large-scale monitoring of the land, air, water and biota for a plethora of pesticides appears to have diminished. Nevertheless, some aspects of the environmental and ecological (including human) data base are deficient (143,149).

   A. Bound residues of pesticides in soils and sediments are being increasingly discussed. These residues are not determinable by the usual extraction procedures used in pesticide analysis (21,22,143,149). The implication is that pesticide residues in soils and sediments may have been underestimated as a result of this methodological deficiency. Increased knowledge must also be obtained on the fate of these materials in the environment and their availability to the biota.

B. In the overall monitoring (20-22,33,91,93-96,135,147) and modeling efforts (38,64,86,98,cf. 116) on pesticides, two segments of the environment and ecosystem appear to have been neglected:

1. Little information is available on the intrusion of pesticides into groundwater (78,97,100,101,135). This environmental assessment is particularly important where the water-table is close to the surface, where water-soluble chemicals are being used and where irrigation is common. Almost no information is available on the dispersion of the compounds when they reach the groundwater system, nor are their decomposition and fate understood.
2. In a related vein, the dispersion of pesticides in the marsh areas of major river systems is virtually unknown. This information would have spin-offs to such compounds as PCBs which might reach a marsh in, for example, the backwaters of the Mississippi River. These marshes serve as important fish and wildlife habitats and must be protected. Management alternatives are difficult to assess if the fate of toxic materials entering the system is not known.

C. Continued public emotion surrounds questions of aerial applications of pesticides (31,66,72,88,95,110,161,168,170). A sincere effort to evaluate the amounts of pesticides reaching the target area, the magnitude and extent of drift, the atmospheric dispersion of the materials and the eventual atmospheric fallout and washout zones is warranted. A large body of meteorological information is now available and major advancements in atmospheric dispersion models have been made which could lead to a fairly rapid resolution of this data base deficiency.

D. Improved design of epidemiological studies for assessing the impact of pesticides on human health (cf. 83-85, 93-96, 136) is urgently needed. Human health effects will in the end determine the approval or restriction of particular pesticides including those presently on the market, those in the testing stage and those yet to be synthesized. Information on pesticide use, fate of pesticides and number and longevity of human exposures to the compound is needed to make a sensible judgement on any compound's acceptability. It is much easier to make these evaluations in a closed system (a manufacturing plant) than in the open environment. However, data base deficiencies are evident in both environmental areas.

E. Since it is impossible to monitor all segments of the environment for all things, increased dependence must be placed on mathematical models to provide the predictive capability needed for judicious, environmental decision-making. Many models have been developed (27,30,38,64,86,98) but their applicability to different regional situations have not been substantiated. Sensitivity analyses are needed to stipulate the minimum information needed to accurately predict the environmental impacts of pesticide use. In this manner, the decision maker is provided with accessibility to alternative solutions and their consequences.

These recommendations focus on pesticide effects on crop productivity, agricultural economy, human health and ecosystem well-being. We believe that this information is essential to the formulation of sound principles and judicious decisions on the agricultural and economic needs for the use of pesticides tempered with wise policymaking in human and environmental health protection.

AGRICULTURAL PRODUCTIVITY AND PESTICIDE USE

According to statistics compiled by the U.S. Department of Agriculture (USDA) from 1975 to 1979 there are about 1,256 million acres of agricultural land in the United States, representing over 55% of the total land area of 2,264 million acres (Figure 6). Almost half of the agricultural land (598 million acres) is grassland pasture and rangeland and almost one-third (382 million acres) is cropland.

Until recently about 20 to 25 million acres of cropland used to remain idle in the "soil bank" because of production surpluses; in addition, about 83 million acres of potential cropland was in constant use as pasture for dairy herds. The land use occupying the largest area of the United States is forestry (748 million acres): 30 million acres of this land is reserved for parks and national forests, and a large fraction (about 180 million acres) serves simultaneously for grazing and is therefore classified as agricultural land. Recent legislation has greatly increased the acreage under restricted (nonagricultural) use.

Farming activities are not well distributed throughout the United States reflecting differences in soils, topography, and climate. The USDA divides the country into 10 major regions (Figure 7). Each is characterized by differences in types of agriculture and each has its own peculiar insect, weed and plant disease problems.

A minor reduction has occurred in the 400 to 410 million acres of cropland used from 1920 to 1950, but this cropland is now producing enough food to feed about twice the United States population it did in 1920 (108), while at the same time affording large surpluses for export (158). Concurrently, however, grassland and pasture have declined seriously from the 832 million acres available in 1900 to the present 681 million acres.

As a result of changing land use patterns, potentially tillable land in reserve in the United States has shrunk from 266 (1974) to 111 million acres (1978 USDA estimate). Of this, only about one-third is "prime" agricultural land, suitable for conversion to tillage without major monetary and energy investment. Thus, about 80% of the best agricultural land is already under intensive cultivation.

Irrigation has increased the area of marginal land used for cropping by 14.6 million acres or 56% since 1945, but this is an energy intensive, environmentally sensitive method of agricultural production. Huge losses in potential cropland and agricultural land resulted from legislation in 1976 (Federal Land Policy and Management Act), 1978 (Public Rangelands Improvement Act), and 1980 (Alaska National Interest Lands Conservation Act), which removed much of the government-owned land in western states (e.g., Wyoming, Colorado) from grazing and provoked the "sagebrush rebellion" or reserved it for national parks (Alaska).

Some agronomists suggest that the productivity of the cropland in use, though still increasing, has been levelling off. Consequently a need for 400 million acres of cropland is projected for the year 2000. Nonetheless,

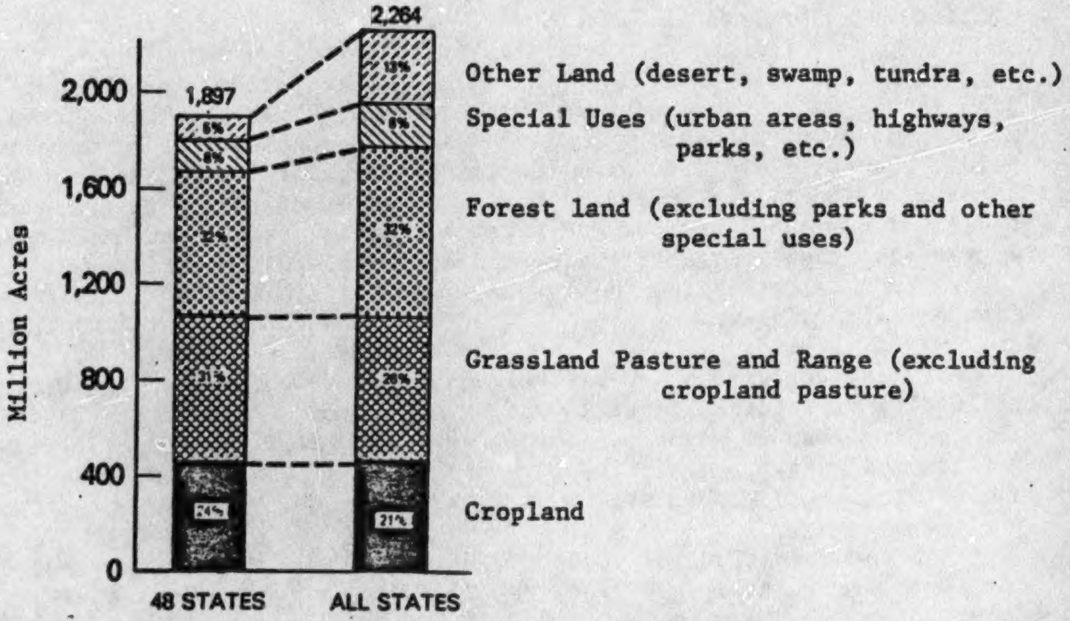

Figure 6. Major uses of land in the United States in 1974 (data from USDA, 1977).

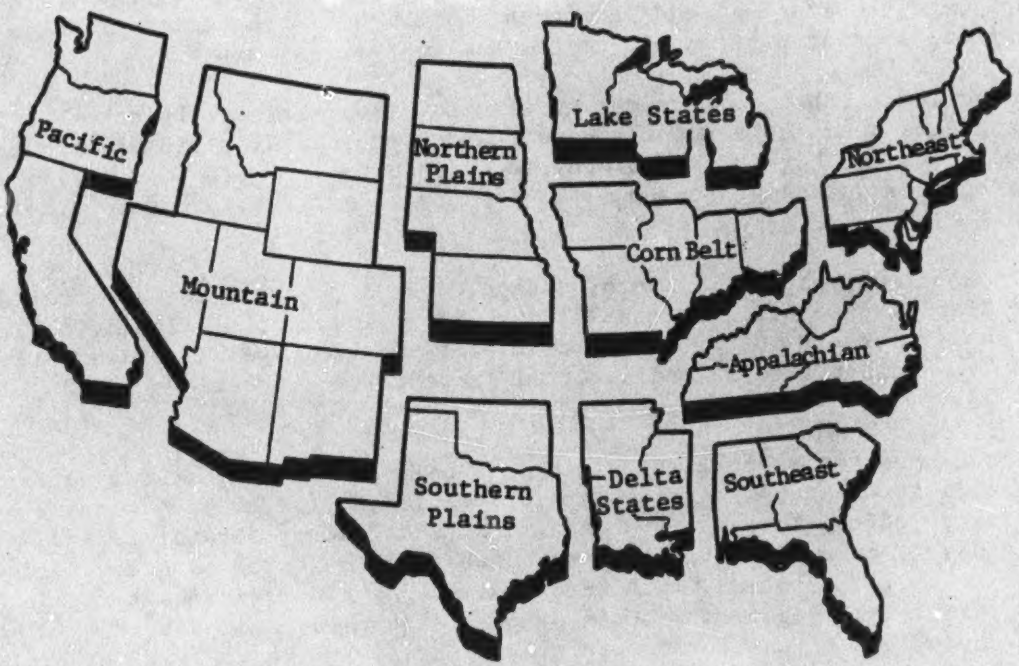
Pacific
Mountain
Northern Plains
Southern Plains
Lake States
Corn Belt
Delta States
Appalachian
Southeast
Northeast

Figure 7. Farm production regions in the United States.

despite tax incentives to continue farming, many farmers are selling off prime agricultural land--their most profitable "crop"--to urban developers, constantly diminishing the present pool of cropland and pasture. Shortfalls in the area and quality of land available for farming are therefore expected.

Agriculture is a major portion of the U.S. economy: the total farm income for 1979 was $146.7 billion (including $61.7 billion from crops and $67.2 billion from livestock), representing over 6% of the gross national product of $2,368.8 billion (158). Agricultural exports in 1979 amounted to $32 billion or almost 12.5% of all exports ($257.5 billion). Agricultural exports are therefore a major component in the U.S. balance of trade, still offsetting a major portion of the current cost of oil imports.

The losses that farmers may sustain to crops because of insects, grubs, diseases and weeds consequently constitute a problem of national importance. These losses are highly variable by region, season and crop, so a wide variety of pesticides is used throughout the country in efforts to control these pests.

Some crops, especially corn, cotton, tobacco, vegetables and fruits, are particularly susceptible to pest damage (50,71,108,116,117,126,127,137). Some published figures (108) for the extent of typical damage are summarized in Table 2. Similar figures are reported in other recent reviews (25,26,108,117, 131,137).

To counteract such damage, more than half of the harvested area for crop production is treated with some type of pesticide (152,153) A summary of the percentages of the acreages treated with insecticides, herbicides and fungicides is given in Table 3. Herbicides and insecticides account for most of the pesticides applied, with herbicides being the predominant type. Row crops receive the greatest amounts of pesticides, hay and pasture the least. For example, 90% of the total corn-growing area was treated with herbicide and 38% with insecticide. Corresponding treatments on cotton were 84 and 60%. Most soybean fields were treated with herbicides, but only 7% with insecticides, reflecting the high resistance of most soybean varieties to insect damage. Orchards are treated extensively with insecticides and fungicides, as are most vegetable crops, such as potatoes and sweetcorn, especially the high value, uniform quality crops used for canning or freezing. The areas devoted to these speciality crops is relatively small but the pesticides used on them represent a significant fraction of total agricultural usage. This reflects the economic importance of these crops, their high sensitivity to pest damage, and the need to maintain quality for good marketability of such produce.

The distribution of pesticide use on agricultural lands by agricultural regions is shown in Table 4. These variations in pesticide use by region are indicative of differences in the types of crop, soils, water availability, climatic conditions, and crop susceptibility to pest damage which dictate the need for pesticide usage. The variability in pesticide usage by crop and by region (Tables 3 and 4) suggests that the compounds are being used judiciously and responsibly for pest control to assure satisfactory crop production.

However, for lack of reliable data, it is difficult to assess the present value of pesticide use in the maintenance of agricultural production or to

Table 2. Some typical losses in unprotected crops caused by insects, disease and weeds; after McEwan (108).

Crop	Loss if unprotected, % Range	Loss if unprotected, % Average	Pest
		INSECTS	
Onions	10 to 98	45	Onion maggot
Carrots	0 to 90	—	Carrot rustfly
Apples	20 to 90	—	Codling moth
Wheat	25 to 75	—	Wireworm
Corn	50	—	Not specified
Field crops	5 to 33	12	Sourfly, wireworm, cutworm, grasshopper
		DISEASES	
Corn	up to 25	15	Southern corn leaf blight
Tomato/curcurbits	—	89	Not specified
Beans	—	76	Not specified
Potato	—	53	Not specified
Celery/parsley	—	73	Not specified
Vegetables	20 to 50	—	Not specified
		WEEDS	
Grain	—	15	Not specified
Wheat	30 to 50	—	Wild oats
Wheat	—	30	Wild mustard
Corn	10 to 30	—	Lamb's quarters
	28 to 100	81	Not specified (IL)
	16 to 93	51	Not specified (MN)
Soybeans	0 to 100	45	Not specified

Table 3. Percentage of crop area treated with pesticides (active ingredients) and percentage of pesticides used on crops in the United States, 1976, (152).

Crop	Herbicides		Insecticides		Fungicides		All pesticides*		Area planted, million acres
	% area treated	% of total herbicides used	% area treated	% of total insecticides used	% area treated	% of total fungicides used	% area treated	% of total pesticides used	
Major crops									
Corn	90	53	38	20	1	NA	92	37	84.1
Cotton	84	5	60	40	9	NA	95	14.5	11.7
Soybeans	88	20	7	5	3	<0.5	90	14	50.3
Peanuts	93	1	55	1	76	16	99	2	1.5
Sorghum	51	4	27	3	-	NA	58	3	18.7
Tobacco	55	<0.5	76	2	30	<0.5	97	3.6	1.0
Rice	83	2	11	<0.5	-	NA	83	1	2.5
Wheat	38	6	14	4	1	2	48	4.6	80.2
Other grain**	35	1	5	1	2	NA	41	1	29.8
Alfalfa and other hay	2	<0.5	7	4	-	NA	8	1	61.0
Pasture and rangeland	1	2	<0.5	<0.5	-	NA	2	1	488.2
Other crops***	67	5	79	20	44	81	NA	16	10.9
All crops	23	100	9	100	1	100	NA	100	839.9
Total usage, million lbs		394.3		162.1		43.2		649.8	

- is None reported
NA is Not available
*Includes miticides, fumigants, defoliants and dessicants, and plant growth regulators.
**Includes oats, rye and barley.
***Includes potatoes, other vegetables, fruits and other minor crops.

Table 4. Percentage of area treated and pesticides used on major crops, hay, and pasture and rangeland, by region, in the United States, 1976 (154,155).

Region	Herbicides		Insecticides		Fungicides		All pesticides*		Area planted, million acres
	% area treated	% of total herbicides used	% area treated	% of total insecticides used	% area treated	% of total fungicides used	% area treated	% of total pesticides used	
Northeast	31	3	11	2	1	<0.5	34	3	18.6
Appalachian	31	8	12	7	2	16	33	10	35.6
Southeast	25	5	14	23	4	59	27	11	31.1
Delta States	47	9	12	26	5	2	49	14	29.9
Corn Belt	55	42	14	12	1	<0.5	56	31	112.1
Lake States	51	12	12	4	-	<0.5	42	9	47.2
Northern Plains	20	12	6	9	<0.5	-	21	10	155.3
Southern Plains	6	4	12	10	1	22	10	6	153.6
Mountain	5	2	2	3	<0.5	<0.5	6	2	191.6
Pacific	11	3	9	4	2	-	14	4	53.8
United States	22	100	9	100	1	100	24	100	829.0
Total usage, million lbs		373.9		130.3		8.1		547.6*	

- is None reported
*Includes miticides, fumigants, defoliants and dessicants, and plant growth regulators.

determine what gains in crop production have accrued from expanding pesticide use. Figures given in recent publications are widely disparate, therefore closer examination of these figures and how they were derived is warranted. It has been suggested repeatedly in reviews appearing in the period 1973 to 1979 (123-128) that despite the use of pesticides, one-third of the potential U.S. production of food crops still succumbs to insects, weeds, disease and other pests, and that the present pesticide use is responsible for saving only 9% of the crop which is harvested. However, these particular estimates are not based on reliable recent production, land use, and pesticide use statistics and are therefore misleading.

These estimates were derived initially from data accumulated by the USDA between 1951 and 1960 and published in 1965 (150). Articles published in 1978 (126,127) and 1979 (128) cited 1973 (123,124) and 1976 (125) papers in which these estimates were given; thereby creating the impression that the information was being updated and was therefore "current." Crop losses of 33% despite pesticide use for 1974 which appeared in the 1976 (125) publication and were reproduced in 1978 (126,127) and 1979 (128) were not derived from actual statistics but were based on "discussions with various pest control specialists in different parts of the United States." There was a serious dip in the yields of two major crops, corn and soybeans, in 1974 due to the corn blight, so this was an unusual year. The figure of one-third damage to crops despite pesticide use must therefore be seriously questioned, even if this happened to be a close "guesstimate" for 1974. Another factor which makes these estimates unreliable is the fact that one and the same figure for agricultural land (890 million acres) was used on every case, although this area did not remain constant over this time period. Moreover, no differentiation was made between cropland, range and pasture.

Similarly, the conclusion (126-128) that pesticide use protects only 9% of the crop from losses due to pest damage is of questionable validity because this estimate is based on old or unsubstantiated data. Also, the claim that farmers receive an average of $4 return for each dollar invested in crop protection is based on this 9% crop loss figure. Furthermore, these estimates are based on old gross monetary farm returns (126-128) and not on current crop production figures. If any rationale for pesticide use is to be based on cash returns, farm profits or at least net and not gross crop values should be considered. Since the cash value of crops is depressed by surpluses and inflated by shortages, as is illustrated by the statistics for corn and soybean production and prices shown in Table 5, it is obviously more accurate to measure the benefits of pesticides in terms of productivity levels and not prices. Crop production statistics (154,155) show that the total crop production and, more importantly, the crop yield per acre have increased substantially over the past 15 years, paralleling the expansion in pesticide use. For instance, the following figures for U.S. production (in billions of bushels) are recorded for the years 1964, 1970, and 1979 (cf. Table 5).

	1964	1970	1979
Corn for grain	3.5 (62.9)	4.2 (72.4)	7.8 (109.4)
Small grains (oats, barley rye, sorghum, wheat)	2.3	3.4	3.9
Soybeans	0.7 (22.8)	1.1 (26.7)	2.3 (32.2)

(Figures in parentheses show the average yield in bushels per acre.)

Table 5. Acreages, yields, production and average prices of grain corn and soybeans, 1964-1979 (154,155).

Year	Corn				Soybeans			
	Area harvested (1000 acres)	Yield per acre (bushels)	Production (million bushels)	Ave. price per bushel ($)	Area harvested (1000 acres)	Yield per acre (bushels)	Production (million bushels)	Ave. price per bushel ($)
1964	55,369	62.9	3,484	1.17	30,793	22.8	701	2.62
1965	55,392	74.1	4,103	1.16	34,449	24.5	846	2.54
1966	57,002	73.1	4,168	1.24	36,546	25.4	929	2.75
1967	60,694	80.1	4,800	1.03	39,805	24.5	976	2.49
1968	55,980	79.5	4,450	1.08	41,391	26.7	1,107	2.43
1969	54,574	85.9	4,687	1.16	41,337	27.4	1,133	2.35
1970	57,358	72.4	4,152	1.33	42,249	26.7	1,127	2.85
1971	64,123	88.1	5,646	1.08	42,705	27.5	1,176	3.03
1972	57,513	97.0	5,580	1.57	45,683	27.8	1,270	4.37
1973	62,143	91.3	5,671	2.55	55,667	27.8	1,548	5.68
1974	65,405	71.9	4,701	3.02	51,341	23.7	1,216	6.64
1975	67,505	86.3	5,829	2.54	53,579	28.9	1,547	4.92
1976	71,300	87.9	6,266	2.15	49,358	26.1	1,288	6.81
1977	70,872	90.7	6,425	2.02	57,612	30.6	1,762	5.88
1978	70,275	100.8	7,087	2.11	63,343	29.5	1,870	6.65
1979	70,984	109.4	7,764	?	70,530	32.2	2,268	?

*Note how depressed yields in 1970, 1974 resulted in temporary price increases.

Similar gains in both total production and yield per acre are recorded for other years and other crops. Occasionally, decreases for a single or a few crops occur in a particular year signifying that special traumatic problems occurred that year (drought, early frosts, floods, rain or hail damage, severe disease outbreaks, insect swarm damage, etc.).

The production gains are undoubtedly the result of several factors: increased acreages planted to the crop in question (not always true, sometimes acreage decreases while production increases); use of higher yielding and/or more pest-resistant crop varieties; improved or increased use of fertilizer or irrigation; improved and increased use of pesticides. It is difficult to isolate the benefits of pesticides from this complex; but unless they do in fact effect substantial economic gains, it is difficult to comprehend why the use of pesticides, particularly herbicides, continues to expand.

In the early 1970's, a series of analyses were performed by the USDA Economic Research Service to examine the economic impact of eliminating several organochlorine insecticides and the herbicide 2,4,5-T (35-37,48, 49,52). Similar studies attempting to isolate the contribution of pesticides to crop production and value unfortunately are lacking for most individual and classes of pesticides now in use.

Some reviews have been compiled recently dealing with crop losses in the United States caused by weeds (1,13,25,26), plant diseases (71,117), and insect pests (117,137). All stress the continuing importance of chemical control of pests. Some suggest that the economic gains from plant protection by pesticides is much greater than those repeatedly reported by Pimentel and coworkers (123-128). The growth in U.S. herbicide use (cf. Figs. 2 and 3) appears justified by the magnitude of crop losses ascribed to weeds on the basis of 1975 and 1976 crop production data; losses of corn, cotton, sorghum and rice alone without the use of herbicides would have been greater than the total of U.S. agricultural exports (1). According to one estimate, a $13 billion or 31% of total crop revenue would have been incurred for 1976 crops had chemical control of weeds been eliminated and replaced by economical nonchemical weed control, i.e., crop rotation, sanitation, biocontrol, etc. (1,13). Other estimates, averaged for the years 1972-1976 and 1973-1977, attributed losses of 11.7% or $7.1 billion (26) or 12.4% or $8 billion (25) annually to losses caused by weeds in U.S. crops, even with present levels of chemical control. These losses were distributed among field crops (70-72%), forage (18-20%), and vegetable, fruit and nut crops (10% of the total loss). Had more acreage been treated, these losses would have been reduced.

Herbicide use has reduced enormously the amount of manual labor and mechanical work needed for weed control (26,139). Overriding importance is ascribed to weed control as a means of maintaining agricultural production, because weeds are a perennial, ubiquitous problem, whereas other insects and disease pests tend to appear sporadically or in epidemics. In view of the decrease in the farmer's share from food prices from 47% in 1950 to 38% in 1980, adequate assurance of productivity by weed control has become an indispensible part of agricultural economy (1,25).

Average losses in agricultural crops caused by insects and mites are placed in the range of 10-12% (137). However, owing to the epidemic, often localized nature of insect infestations, losses can vary considerably from year to year and from one geographic region to another. No substantial reduction in crop losses from insect damage is said to have taken place over the past 30 years (137). Insecticide use has decreased for some crops (e.g., cotton, tobacco, apples, some field crops), increased for others (e.g., corn, wheat, citrus and other fruits, and vegetable crops) (137); total insecticide use is predicted to decrease by one estimate (137), increase by another (5). While the need for continued chemical control of insects is clearly supported by the magnitude of crop losses due to insect damage, apparently present committment to research, development and implementation of management programs is only sufficient to help agricultural production hold its own in the struggle against insect pests (137).

For lack of recent surveys, crop losses in the United States now prevented by control with fungicides and nematicides (117) and plant diseases (71) are hard to determine. National programs for disease loss surveys such as exist in the United Kingdom and Canada have not been conducted in the United States since 1965 (71). Since losses to disease were placed at $3.25 billion in 1965, minimum losses of $6-7 billion were extrapolated for 1976 (71). In the absence of fungicides and nematicides, minimum crop losses of $1.7 billion and $1.6 billion were estimated for 1968-69 farm values, but more recently estimates of or extrapolations for the costs of fungus and nematode damage were not provided (117).

Perusal of the scientific literature confirms that the types of pesticides now in use still have substantial benefits for crop production and quality (cf. Table 2). Most recent reports on pesticide use, whether on croplands or pasture, record higher yields and other improvements when specifically compared to untreated controls. Some effects are direct, others indirect. For example, insecticides increased the yield of rice by 8% (53), nematode control increased small grain yields 40-73% (73), fungicides increased the yield of wheat grain by 33% (10), insecticides tested over three years increased the yield and quality of cotton (165), and pesticide combinations increased the size, quality and yield of vegetable crops (46,51,145,146). Nematicide application was the only method of control that increased the yields of sweet potatoes (76) and tomatoes (75) substantially. Soil fumigation increased the sugar yield in beets and sometimes the grain yield in subsequent barley crops (105). Insect control can reduce not only insect damage but also the transfer of insect-borne plant diseases (8). High pesticide specificity and biodegradability now largely eliminates danger to neighboring and subsequent crops (39).

Herbicide use in pasture or rangeland increases the yield of grass, forage, protein and consequently even wildlife; desirable plant species replace undesirable brush, so that water conservation is also improved (11,24,56,68,69,138). Although some weeds, e.g., phorbs, may become resistant after several years of application, herbicide rotations or combinations can overcome this problem (138).

Sometimes beneficial effects of pesticides are not achieved, but such reports are rare. For example, use of inappropriate herbicide/insecticide combinations can affect cotton plants, reducing yields; but proper instructions for use can overcome this problem (12). Some injury and reduced second yields of rice were observed on repeated treatments with one phenoxy herbicide combination in Texas, but not with another (47). This appears to be an unusual situation when compared to information from other rice growing areas (52,140). Insecticides reduced injury in peas in sensitive areas, but did not increase yield nor raise the quality to that of certified seed. Such quality improvement peas was achieved only by a five-year crop rotation

Table 6. Some major advantages and disadvantages of herbicides and insecticides

Herbicides		Insecticides	
Advantages	Disadvanates	Advantages	Disadvantages
1. Reduce competition to useful plants from weeds for space, light, fertilizer, soil minerals and water.	1. May inadvertently kill some soil invertebrates or microorganisms.	1. Reduce or eliminate insect damage to plants and fruit.	1. Inadvertently kill useful insects, e.g. pollinators (flies, bees), predators (mite-eating lady birds).
2. Reduce energy and manpower inputs for soil preparation.	2. May leave toxic or harmful residues in produce, soil and water.	2. Eliminate many insect carriers of plant diseases.	2. May kill or taint fish if they reach surface waters.
3. Increase yield and quality of food, forage and fiber.	3. Leachate or eroded soil may introduce harmful residues to ground or surface water.	3. Increase yield and quality of food and fiber.	3. May reduce valuable bird species (eagles, falcons, pelicans, ospreys)
4. Reduce soil erosion (no-till systems)	4. May harm neighboring or subsequent crops by drift or carryover.		4. May deposit low levels of toxic, carcinogenic, teratogenic or mutagenic residues on plants or in air, soil and water.
5. Control flooding caused by clogging of drainage systems by weeds.	5. May increase soil erosion by eliminating weedy cover crops.		5. May pose health hazards to applicators.
6. Eliminate many poisonous or allergenic weeds.	6. Spills in water can cause fish kills.		
7. Reduce hazard of brush fires in range and forest lands.			

(145). Herbicides increased the protein content of corn (115) but this apparently made the crop more attractive to pests (corn leaf aphids, European corn borers and southern corn leaf blight). Measures to control these pests were not applied, but would have presumably overcome the increased infestation problem.

Although development of resistance by pests to some pesticides—once a major problem with the organochlorine compounds (164)—is still occasionally reported, reductions in crop yield caused by long-term application of pesticides have not been documented. No loss of soil fertility was recorded due to pesticide treatments or tillage practices in continuous corn production on a wide range of soil types from 1962 to 1973 (160). Only poorly drained soils sustained pest losses, but these could be controlled by crop rotation. No tillage with weed control gave greater yields than plowed treatments. In no-till agriculture, application of sublethal levels of herbicides can increase productivity by leaving about 50% of grass cover, which controls soil erosion and can be used for grazing, while still providing good weed control for corn (45).

On balance, positive effects of pesticides (Table 6) seem to outweigh negative effects, even though most of these effects have not been quantitatively assessed.

If the figure of 9% reduction in crop damage due to pesticide use (126-128) is accepted, figures given in the same publication simply that elimination of pesticide use would necessitate development of 60 million more acres of cropland to keep agricultural production at its present level. The land available in the "soil bank" (ca. 25 million acres) plus the 34 million acres of prime agricultural land available according to the 1978 USDA estimate of the nation's reserves is just about sufficient to satisfy this requirement. Cultivation of this land would likely create shortages in other land-use categories, e.g., pasture and forest. These estimates do not include the additional land required to meet the food, fiber and forage needs of expanding U.S. and world populations. If pesticides provide more than 9% crop protection, as other publications tend to suggest (61,108,116,139), even greater areas of land would be needed to offset production losses if pesticide use were eliminated.

In consequence, continued use of pesticides seems inescapable. The question whether sufficient quantities and varieties of acceptable pesticides to maintain or increase current agricultural production therefore becomes critical. Some current trends in farming practice, e.g. organic farming (90,157) and integrated pest management programs (6,54), may reduce some pesticide use. Others, e.g., no-till or low-till agriculture (14,121,122), and irrigation agriculture, may increase pesticide use. Insufficient data are available to forecast what the overall effects of these trends will be. However, preliminary data indicate that in some cases, agricultural production will be substantially increased. Average yields of soybeans of 65 bushels per acre are achieved with no-till agriculture with weed control using herbicides because rows can be planted with only 7-inch spacings, versus 36-inch spacings if mechanical weed control is practiced. The higher number of plants per acre increases the yield to twice the national average of about 32 bushels per acre.

MONITORING DATA AND PROGRAMS

Who is Performing Monitoring Programs

Both beneficial and detrimental effects of pesticides are regularly measured. However, there are substantial differences in the ways that the monitoring programs are organized and the resultant information used.

The benefits of pesticides are usually measured incidentally during work designed to determine guidelines for their appropriate use. Such work is performed in field plot trials conducted by extension scientists at Land Grant Universities and funded through the Science and Education Administration of the U.S. Department of Agriculture. In the traditional approach used in applied agricultural research, yields from areas treated with pesticides are compared with those from control areas receiving no treatment or other non-chemical pest-control measures, e.g. hand or mechanical weeding. Yield data are usually published only in extension bulletins which receive only limited local or statewide circulation (cf. 15,60). Collation and integration of information on a regional or national basis is occasionally made by professional societies at regional meetings or in national reports, e.g. the 1976, 1977 and 1978 Insecticide and Herbicide Tests published by the Entomological Society of America, the 1973-1977 Fungicide and Nematicide Tests published by the American Phytopathological Society, the research reports of the North-Central Weed Conference and the Western, Southern, and Northeastern Weed Science Societies. These reports generally document the enormous efficiency and cost-effectiveness of chemical versus other means of pest control and often recommend protocols for improved or extended pesticide use. At present, within the Federal Government responsibility for integrating and evaluating pest management data resides in the Pest Control Branch of the Natural Resource Economics Division of the Economics, Statistics and Cooperatives Service of USDA, but no directive exists for routine monitoring of pesticide efficiency and use. There are no computerized data banks with assemblies of chemical pest management data.

Monitoring of adverse effects of pesticides, on the other hand, is organized primarily at the Federal Government level, largely as a consequence of historical developments.

The world was rudely awakened to the potential hazards of uncontrolled pesticide use by the appearance in 1962 of Rachel Carson's "Silent Spring." Although subsequent objective appraisal by a subcommittee of Congress revealed most of Carson's claims to be grossly exaggerated or erroneous (169), the problems highlighted by her book and many like it that followed prompted legislation designed to ensure responsible use and control of pesticides, notably the 1972, 1975, and 1978 amendments to the Federal Insecticide, Fungicide and Rodenticide Act of 1947, and the Toxic Substances Control Act of 1976.

In order to ascertain how much damage had been done by early excessive and uncontrolled pesticide use, how the situation improved after introduction of controls, and whether unnoticed long-term effects on the environment were continuing, programs to monitor the levels of pesticides and their residues and breakdown products in various phases and organisms in the environment have been created at the national level and in many states; measurements have also been made in academic and private and industrial research laboratories.

Within the Federal government the main responsibility for pesticide monitoring on a nation-wide scale resides with the Office of Pesticide Programs of the U.S. Environmental Protection Agency, mainly in its Survey and Analysis and Hazard Evaluation Divisions. Research funded by the U.S. EPA through the National Pesticide Monitoring Program and the National Soils Monitoring Program (20-22,33,93-96,136) and performed at various university and state laboratories provides an excellent source of pesticide residue information. The bulk of the findings are published in scientific journals such as the Pesticide Monitoring Journal the Journal of Environmental Quality, and Environmental Science and Technology. Findings up to 1975 have been recently reviewed (83).

In addition, through its regional offices, the U.S. EPA conducts extensive "surveillance" activities. For instance, they created a national network of about 1000 stations that conduct annual surveys on the content of the whole spectrum of "hard" organochlorine pesticides in fish. For example, about 100 samples from 29 stations are analyzed yearly in Wisconsin; more or fewer samples are conducted in other states depending on the importance of the problem for each locality. The data are stored in easily retrievable from in the U.S. EPA's STORET computer data base. Current data indicate that levels of these persistent pesticides are falling in fish taken from rivers and smaller lakes but are remaining rather constant in some fish from the Great Lakes.

Other Federal Government agencies also are conducting parallel monitoring programs. The USDI Fish and Wildlife Service conduct extensive surveys of hard pesticide residues in fish, game, birds and wildlife and the U.S. Geological Survey also has extensive activities in this area as well as in water analysis. The USGS data are stored in their WATSTORE data bank. Lists of agencies, organizations and individuals involved in pesticide monitoring are available from the USGS National Water Data Exchange (NAWDEX). Data are not collected in this program: contributers must be contacted individually for permission to access their data. Monitoring activities by state and local governments and by industry or consultant groups are usually not of national scope but concentrate on perceived or suspected local problems, for example, fish kills resulting from accidental pesticide spills or herbicide runoff from freshly treated fields following unexpected violent storms. Unfortunately, there is apparently no longer any comprehensive coordination of pesticide monitoring activities, an exercise once performed by the President's Council on Environmental Quality. There is probably massive overlap in many monitoring programs, even at the Federal agency level, and the value of the stored data is questionable, since differences in the nature of the samples examined, the analytical sensitivity, and the extent of quality control are not recorded. For instance, some programs monitor whole fish, others only muscle tissue (fillets), fatty tissue, individual organs (liver), etc.

At state levels, pesticide monitoring in food usually is performed by state agricultural departments and in soils, air and water by state agencies concerned with public health or consumer or environmental protection; these agencies have a variety of names usually related to "natural resources", "environmental quality" or "environmental protection." Pesticide levels in produce sold in interstate commerce as determined in market basket surveys are reported to the Food and Drug Administration and stored in their computerized data bank. State agricultural agencies also perform quality control analyses on the materials sold for application, in order to corroborate the formulations specified on the pesticide labels. Lately major pesticide manufacturers (including Dow, DuPont, Monsanto, and Union Carbide) have been performing broad-scale monitoring programs, exhibiting an exemplary attitude of responsibility and concern for the appropriate, safe use of their own products. Often these companies have the best know-how, trained manpower and sophisticated instrumentation for performing the types of analyses necessary for a good monitoring program. Some inter-industry programs also are organized through the National Association of Chemical Manufacturers. Numerous analyses are also performed for private clients by several commercial laboratories (e.g. Raltech, formerly WARF in Madison, WI, Battelle in Columbia, OH, Southern Regional in Birmingham, AL, and ADL in Fort Collins, CO) but the results are usually confidential.

Kinds of Measurements Being Made

Because of significant changes over the past decade in the types of pesticides being used, improvements in the capabilities of methods and instruments for pesticide analysis, shifts in emphasis of environmental concern, and budgetary restrictions, the types of pesticide measurements being made and their frequency have altered considerably.

Unequivocal detection and accurate assay of traces of pesticides or their breakdown products in environmental or biological samples are difficult undertakings (21,143,149). Unfortunately, as decried in a recent review, (85), "Mistakes in identification of molecules by inexperienced analysts, particularly in the area of environmental chemistry, have caused premature reporting of erroneously identified residues." Because of the sensationalism associated with the "detection" of hazardous levels of pesticides in the environment, many reports of such uncorroboratable "discoveries" continue today, often appearing in the public press rather than in reports in government documents or scientific journals subject to peer review and thus creating environmental scares and unnecessarily alarming the public. Such irresponsible actions by a minority of scientists seeking notoriety highlight the need for reliable, well coordinated monitoring programs.

The pesticides of greatest environmental concern, the organochlorine compounds, happen to be easiest to analyze, since they are easily separated by gas chromatography and assayed using electron-capture detectors, which respond well to their high content of chlorine atoms. Since the prohibition of DDT, aldrin, dieldrin, lindane, chlordane, heptachlor, and similar chlorinated hydrocarbon insecticides, the federal monitoring programs have detected statistically significant (i.e. real) diminutions in the levels of these compounds and their metabolites in a vast array of environmental samples and organisms monitored. Measurements for organochlorine residues have been made in soils, plants and food, water, fish, birds and other wildlife, and aquatic invertebrates, and in human blood, urine, milk and even adipose tissue. A number or recent articles and reviews have indicated that the levels of chlorinated pesticide residues in such samples and thus the seriousness of environmental contamination with these compounds is decreasing (20-22,33,85,91,93-96,130,135,144,147,148,171). Although concern for the levels of these compounds is fading, monitoring of chlorinated hydrocarbons is nevertheless continuing because: 1. organochlorine compounds are relatively easy to determine, 2. their monitoring parallels the monitoring of the non-pesticide polychlorinated biphenyls (PCBs), which may be ubiquitous and more serious environmental pollutants, 3. any possibility of long-term chronic toxicity should be assessed, and 4. human exposure to a few permitted low-usage chloro-compounds such as toxaphene and methoxychlor is continuing.

Detection of other organic pesticides in the environment is much more difficult. Generally, these compounds 1. do not contain an element such as chlorine that makes them easy to detect and estimate quantitatively, 2. do not persist for long times in the environment or in organisms (cf. Figure 8), 3. do not become enriched in human or animal tissue (unlike chlorinated hydrocarbons which dissolve easily in fats and therefore concentrate in fatty tissues, milk, and blood lipids). A routine monitoring program for these pesticides is also difficult to justify because 1. it is much more sophisticated and expensive than that required for organochlorine compounds, 2. most of these pesticides are of low toxicity to non-target organisms, i.e., humans, fish, and wildlife. Correlations have recently been made among acutely and chronically toxic levels of 75 pesticides and a variety of key test organisms which should simplify and reduce the amount of testing that must be done for satisfactory pesticide monitoring programs (83,84).

So far, no serious or large-scale detrimental response to chlorine-free pesticides could be documented, even though some, such as parathion, aldicarb or carbaryl are relatively toxic to mammals. Possibly some of these pesticides could seriously affect children, the elderly or the debilitated. Restricted monitoring of selected compounds is therefore warranted and is in fact being performed, with a view towards creation of acceptable standards for food and drinking water. For example, the U.S. EPA is examining 600 samples from 16 states for their content of aldicarb—a relatively toxic water-soluble nematicide used on potatoes and vegetable crops and claimed to be present in hazardous levels (still unproven) in the groundwater below irrigated fields in Long Island, Central Wisconsin, Florida, etc. A similar survey is being conducted by Union Carbide, the manufacturer of the product. Oxidation products of this compound, which may be formed in the environment or after ingestion by animals, must be included in the survey, because one—the sulfone—is more toxic than the parent compound, while another—the sulfoxide is less toxic.

Great ingenuity is called for to recognize and analyze such problems. To determine whether humans or animals have ingested or inhaled some pesticides, it becomes necessary to search for their metabolities (for example α-naphthol derived from the insecticide carbaryl) in urine or blood samples. Usually chlorinated derivatives of the metabolites must be made to make them as amenable to accurate detection and assay as organochlorine pesticides. Most monitoring programs have so far concentrated on insecticides, since it seems more likely that insecticides will adversely affect human, wildlife, and fish metabolism than herbicides.

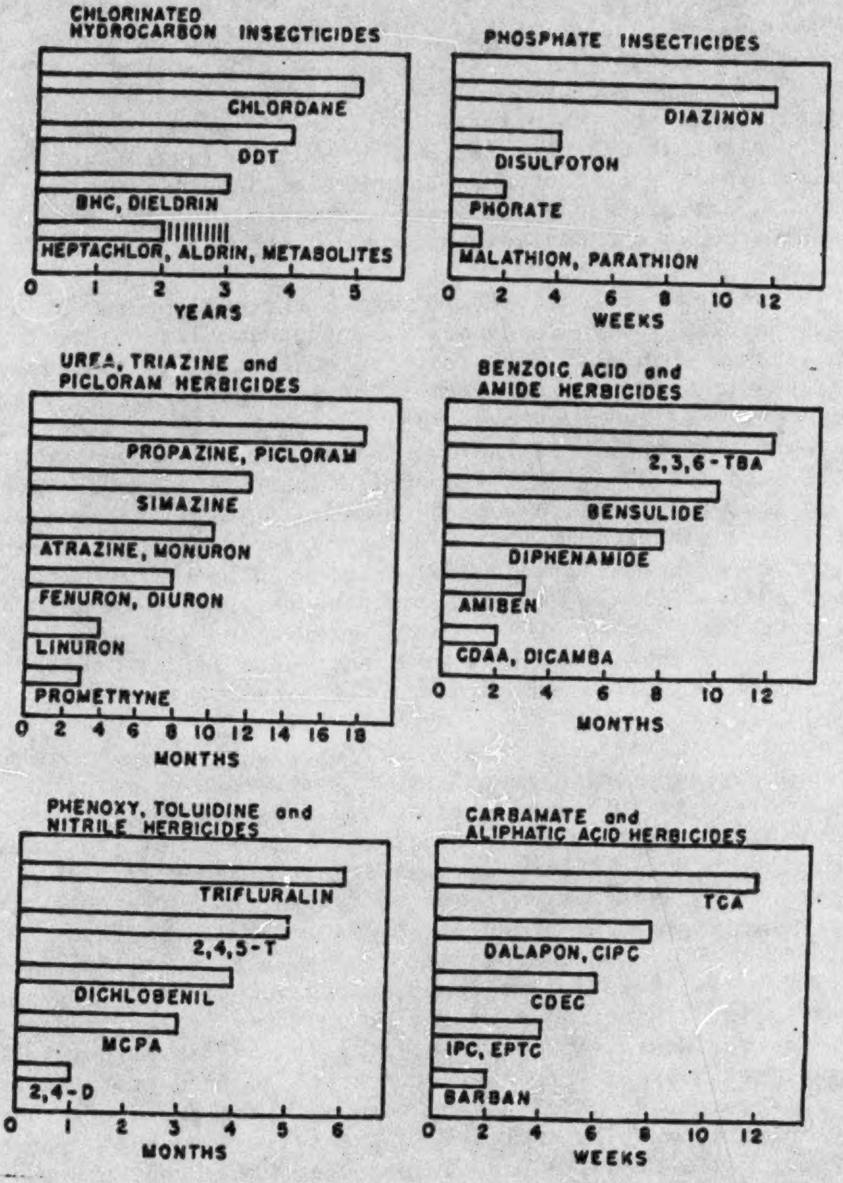

Figure 8. Persistence of pesticides in soils (81,82).

Monitoring for "soft" types of pesticide is a one-time affair. If it is recognized that real problems exist, use will be discontinued and substitutes found. In any case, the modern trend is toward pesticide rotation in parallel with crop rotation; this prevents buildup of any one compound and development of pest resistance, and application only as needed--as dictated by good economics and good environmental protection, a step toward integrated pest management (cf. 6,54,106,116,164).

ENVIRONMENTAL DISTRIBUTION AND FATE OF PESTICIDES

Pesticide Transport in the Environment

Pesticides may enter the aquatic environment through atmospheric transport, subsurface drainage, and surface runoff and sediment transport.

Atmospheric transport

The atmosphere is contaminated with pesticides by drift during application; volatilization, during application or from soil and other surfaces; and wind erosion (168).

Drift is that portion of a pesticidal spray application that is moved away from the target area by wind or other meteorological factors. The quantity and extent of dispersal of drift loss are influenced by pesticide formulation, prevailing meteorological conditions (wind velocity, temperature, humidity) and method of application (66,110,170). High temperatures and windy conditions as well as fine particle or drop size (dusts or aerosols) accentuate drifting. Drifting is more apt to occur with aerially-applied pesticides than with ground-applied pesticides. Particles are now electrostatically changed or spiked with tacky substances to improve adhesion to plant surfaces.

Volatilization has been recognized as a major pathway for loss of pesticides from surfaces including soil, plant, and water. The factors and mechanisms of volatilization losses in soils are reviewed by Spencer et al. (142) and Guenzi and Beard (52). After application-related volatilization has occurred, the remaining pesticides ultimately reach the soil. The principal factors controlling the rate of volatilization in soils are the physical and chemical properties of the pesticide, adsorptive characteristics of the soil, soil water content, air movement, temperature, pesticide concentration, and diffusion. The vaporization rate of a pesticide is related to its vapor pressure, but once it is in contact with the soil its vapor pressure is modified by climatic and soil (edaphic) factors.

Field measurements indicate that volatilization is evident for soil-incorporated and surface-applied pesticides. However, more significant losses may occur with the latter method of application as observed for many organochlorine insecticides. It appears that incorporation of the more volatile pesticides into the soil is necessary to prevent excessive loss to the atmosphere, but under normal farming practices pesticide incorporation is not always possible.

Pesticide-laden dust may originate from dislodgement of the soil-pesticide complex due to wind erosion (31). Wind erosion can provide an important atmospheric source of pesticides when the pesticides are redeposited on watersheds and waterbodies.

Pesticides dispersed in the atmosphere become associated with airborne particulate matter and, as such, are capable of being transported (31). Their distribution away from the site of application is dependent on the prevailing wind movement and the rate of fallout and rain washout. The widespread distribution of DDT in the environment is attributed to the transportation and subsequent fallout of airborne particulate materials (132).

Subsurface drainage

Pesticide contamination of groundwater can occur through leaching. Downward movement of agriculturally-applied pesticides is controlled by soil and pesticide properties and climatic factors (2,62,167). Leachability of a compound depends primarily on the degree to which it is adsorbed to soil colloids. For nearly all pesticides, adsorption is related directly with organic matter content and occasionally with clay content. Pesticides are leached more readily in coarse-textured than in fine-textured soils because the latter contain more clay and generally more organic matter. Furthermore, the rate of water infiltration is relatively faster in coarser-textured soils. The solubility of pesticides play an important role in their movement in the soil since solubility limits the concentration of the compound in the soil-water phase. Solubility--which is largely dependent on the chemical constitution of the compound--is shown to be correlated inversely with adsorptivity. Thus, pesticides of high water solubility are more subject to vertical movement than those of low water solubility. The transport of pesticides through the soil is conditioned by the amount, intensity and frequency of percolating water. Water facilitates desorption as well as dissolution of particulate or adsorbed compounds.

Numerous studies have been conducted to determine the relative mobilities of pesticides in soils and are summarized by Helling et al. (62). The organochlorine insecticides--which have limited water solubility--are the least mobile, followed by the organophosphorus insecticides. The water-soluble acidic herbicides are most mobile. Most of the pesticides, such as triazines, phenylureas and carbamates have intermediate mobility. Within a diverse group of pesticides, relative mobility is related essentially to solubility.

The persistence of a pesticide may also determine its movement in the soil. Persistent compounds because of their longevity have a greater chance to move with the percolating water than less persistent compounds.

Available information indicates that pesticide contamination of groundwater under normal agricultural usage is minimal (78,101,111,135). However, groundwater contamination may occur in agricultural areas with sandy soils and shallow water tables (97,135).

Surface runoff and sediment transport

Runoff consists of the runoff waters and suspended soil particles (sediment) dislodged by erosion. Pesticides present on agricultural land may be transported through surface runoff either in solution and/or as adsorbed molecules on suspended, eroded soil particles. Since surface soils are susceptible to erosion, pesticides retained in the plow depth layer are potentially transportable by surface runoff. Pesticide concentrations are generally higher for the eroded soil particles than in the runoff water (58,59). This emphasizes the importance of reducing erosion by sound soil management and conservation practices to minimize the pesticide load of the runoff, particularly the adsorbed pesticides.

Surface runoff from surrounding agricultural watersheds has been implicated as the major avenue of pesticide contamination of aquatic systems (29,99,111,113), especially the organochlorine insecticides. Studies have been made to quantify the levels of pesticides contributed by runoff both in small agricultural watersheds (129) and, to a limited degree, in large watersheds (28). Results reveal that only low levels of pesticides are transported by runoff even with organochlorine insecticides. Even so, the possibility exists that persistent pesticides associated with the soil are subjected continually to runoff, thereby adding a low-level, but continual amount of residues to aquatic environments. A study in the Mill Creek watershed in Michigan, reveals that pesticides--particularly organochlorines like DDT and dieldrin--are still a significant nonpoint source of contamination to Michigan rivers and consequently the bordering Great Lakes (18). The major land use in this watershed is orchards. The concentrations found are in the part per billion and trillion levels but are still significant in terms of their effect on aquatic organisms due to biomagnification. Results are supported by the fact that pesticides such as DDT and dieldrin are found in Great Lakes fish and are responsible for the banning of commercial fishing for Coho salmon, etc. Prevention of sheet erosion would certainly be a measure that would reduce the amount of pesticides entering the Great Lakes. Runoff losses depend on the nature of the pesticide, soil properties, and climatic factors. Modifying factors include topography, vegetative cover, rate and frequency of application, time between application and first rainfall, and size of the watershed.

The amount of residues available for transport is dependent largely on the persistence of the pesticides. Persistent pesticides, because of their tendency to accumulate in the surface soil, have greater runoff potential than the less persistent pesticides. Dissipation processes affecting pesticide persistence are discussed in the following section.

Persistence and Degradation

In order for a pesticide to be effective it must possess a certain degree of persistence. Persistence beyond the critical period of control creates residue problems. However, pesticides remaining in soils and those present in aquatic systems and the atmosphere are subjected continually to dissipation processes (Figure 9) acting singly or interactively. The mechanisms of dissipation include adsorption by soil particles, chemical and biological degradation, absorption by higher organisms, volatilization, leaching, and runoff. The last three are mechanisms for transport of pesticides from one segment of the ecosystem to another. The dissipation processes may be similar in all parts of the environment but the rates may vary because of the differences in prevailing environmental conditions in different systems. While pesticides have inherent but varying degrees of persistency because of their chemical nature, their longevity in the environment is modified by edaphic, climatic and limnological factors (Pionke and Chesters, 1973). Figure 8 summarizes the soil persistence of major pesticide groups. The data

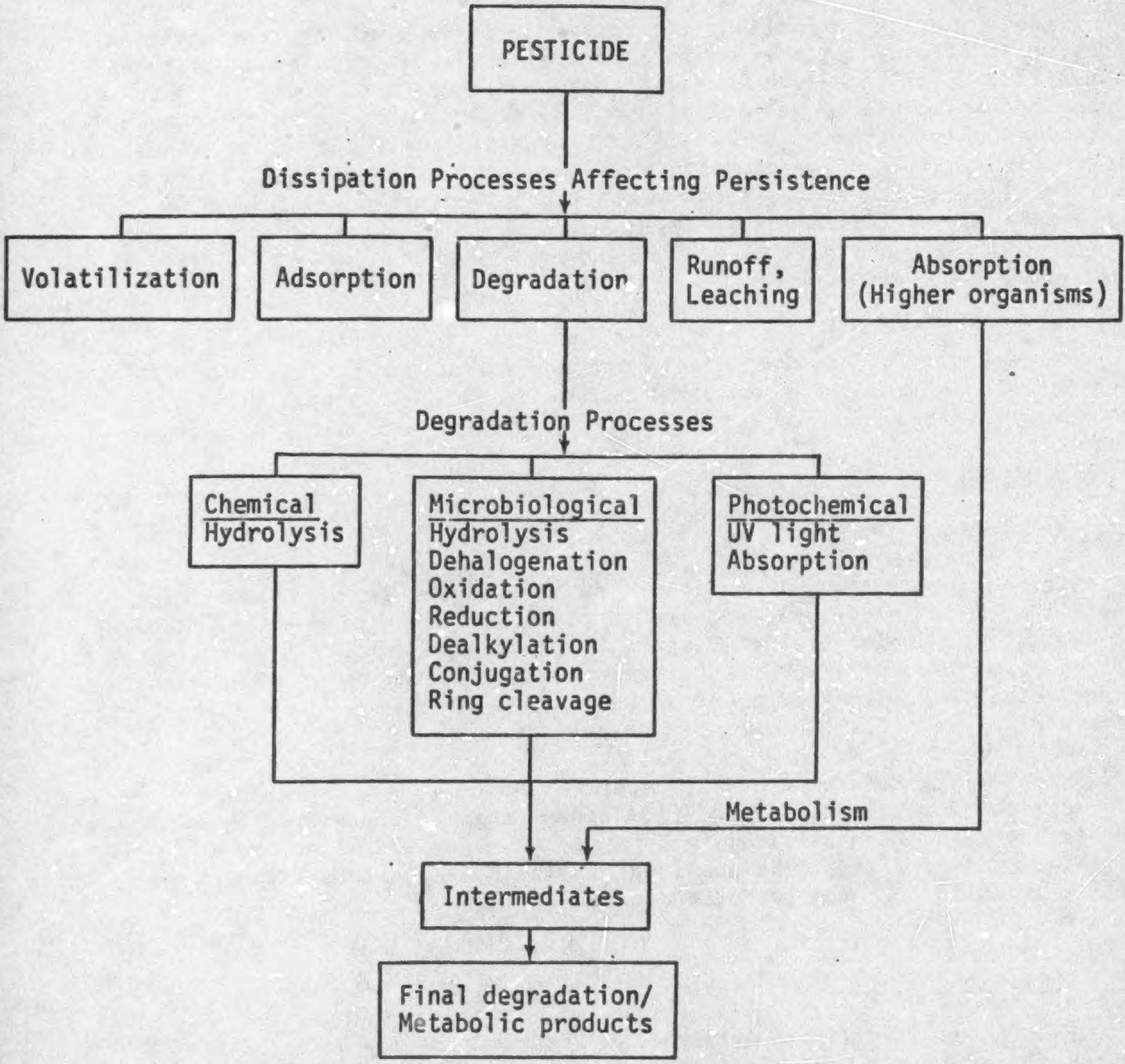
PESTICIDE
Dissipation Processes Affecting Persistence
Volatilization
Adsorption
Degradation
Runoff, Leaching
Absorption (Higher organisms)
Degradation Processes
Chemical
Hydrolysis
Microbiological
Hydrolysis
Dehalogenation
Oxidation
Reduction
Dealkylation
Conjugation
Ring cleavage
Photochemical
UV light
Absorption
Metabolism
Intermediates
Final degradation/ Metabolic products

Figure 9. Dissipation and degradation of pesticides in the environment.

were compiled from 80 sources concerned with pesticide persistence in soils.

Adsorption

Adsorption is an indirect mechanism of dissipation from the environment because it affects degradation rates and reduces pesticide bioactivity and volatility (7,57,62,167). Degradation rates of pesticides may be decreased or increased by adsorption depending upon the mechanism by which the compound is degraded. Adsorption by soil, sediment or particulate matter can stabilize pesticides against biodegradation while, in some cases chemical degradation is accelerated. Furthermore, the availability of adsorbed pesticides to organisms may be reduced markedly.

Degradation

Figure 9 shows the degradation processes and reaction mechanisms. Pesticides can be degraded to other compounds microbiologically by soil and aquatic microorganisms and nonbiologically by photochemical and chemical reactions.

Chemical degradation

Chemical hydrolysis is an important step in the degradation of many pesticides (7). Hydrolysis appears to be catalyzed by adsorption. Several investigations indicate that adsorption-catalyzed degradation in soils is important particularly for the triazine herbicides and the organophosphorus insecticides. Evidence of chemical hydrolysis of some of the organochlorine insecticides in soils has also been reported.

Although certain pesticides are able to undergo rapid chemical degradation, formation of degradation products as persistent as or even more persistent than the parent compound may occur. For instance, among the degradation products of diazinon is diethylthiophosphoric acid which is more stable in soils than the parent compound (92).

Photochemical degradation

Pesticides that absorb ultraviolet light energy may undergo photodecomposition. Photochemical reactions involve isomerization, substitution or oxidation. Photochemical degradation has been demonstrated for a wide range of pesticides including organochlorine insecticides and several herbicide groups such as the benzoic and phenylacetic acids, triazines, ureas, dinitroaniline and picolinic acids, and bipyridyls (34,134).

The practical significance of photochemical degradation in soil is still not certain because the amount of ultraviolet light in sunlight reaching the earth's surface is small. Futhermore, adsorption and microbial degradation are able to compete favorably with photochemical degradation. However, photochemical reactions may be of considerable importance in the decomposition of airborne pesticides and pesticides present on soil and plant surfaces. These transformations not only affect the persistence but also the toxicity and other physiochemical activities of pesticides.

Microbial degradation

Microbial metabolism is considered to be the major pathway of pesticide degradation in soil and aquatic environments. The efficiency of this pathway depends upon the microbial population, which is affected by such environmental factors as temperature, moisture and organic matter content, aeration, pH and other edaphic and limnological factors. Intensive studies have been made on the biochemical mechanisms by which microorganisms degrade pesticides (3,4,63,80,81,163). Biochemical reactions involve hydrolysis, dehalogenation, dehydrogenation, dehydrohalogenation, oxidation, reduction, alkylation, dealkylation, conjugation, ring and ether cleavage, and condensation (Figure 9). Similar metabolic processes and degradation products may be found in soil and aquatic systems but rates of degradation may vary because of differences in microbial activity, substrate composition, pesticide concentrations, and other environmental conditions (101,118).

Pesticides differ in their resistance to microbiological degradation. Some are resistant to biodegradation while others are easily biodegradable. This varying degree of resistance is attributed (80) to two main causes, namely, 1. due to its chemical structure, the pesticide is inherently resistant or susceptible to microbiological attack, and 2. the pesticide although biodegradable may become largely or totally unavailable for microbiological degradation due to the influence of environmental factors and interactions. Strong adsorption of many pesticides such as the organochlorine insecticides and cationic herbicides by clay minerals and organic constituents limits the rapid degradation of these compounds in soil and aquatic systems.

Generalizations can be made on the relative resistance of pesticides to microbiological degradation in soils and aquatic environments as indicated by numerous studies summarized in several reviews (63,80,81,129,163): 1. organochlorine insecticides are the most resistant to microbiological degradation among the pesticidal groups, 2. the organophosphorus and carbamate insecticides are degraded fairly rapidly, 3. most of the herbicides are degraded primarily by microorganisms in relatively short periods, and 4. some fungicides are degraded microbiologically; however, more intensive investigations are needed, particularly on the mercury- and arsenic-containing fungicides.

Uptake by higher organisms

In order for systemic pesticides to be effective they must be absorbed by the target organisms. Pesticides can also get into the systems of non-target organisms through root or foliar absorption by plants and ingestion or contact of contaminated food and water by animals. Nash (112) reviewed the plant uptake of pesticides from soils.

Numerous investigations point to the fact that many of the pesticides absorbed are metabolized (17,81,104,120). Some compounds may remain unaltered in the organism's system or as--in the case of animals--be excreted as the parent compound. The metabolic fate of pesticides in higher organisms is influenced largely by the translocation of the compound, enzyme systems of the organism, and the nature of the microbial population present in the animal's digestive tract. Processes of metabolic breakdown of pesticides appear to be similar in higher organisms and microorganisms.

The ability of higher organisms to metabolize pesticides in their systems may be an important mechanism of detoxification thus reducing the hazard of residues in food.

An ideal pesticide should not only be effective against the pest it is controlling but should degrade to non-toxic metabolite(s) within a reasonable period of time. However, evidence indicates that many pesticides are degraded to compounds equally or more toxic than the parent compound. For example, DDE and TDE (DDD), the degradation products of DDT, possess insecticidal properties and are as persistent as the original compound. Other pesticides may degrade to less active or completely innocuous compounds. Intermediates or terminal metabolites of many pesticides have not been clearly identified, nor have their possible toxicity and persistence in the environment. Toxic and persistent degradation products therefore add to the hazards of using pesticides. Another problem of residues is the complexity and variety of compounds used as pesticides.

Extent of environmental contamination

Under normal pest control operations, pesticides are applied well below the lethal concentrations established for several organisms including man (111,133). For almost three decades of wide usage of pesticides, direct lethal effects are uncommon except in cases of inadvertent use and occupational exposure to the chemicals. Over a 6 year period, only 8.2-9.6 of each 100,000 hospital admissions were due to pesticide poisonings. Less than 50% of these poisonings were intentional, but 58% of the fatalities were intentional (136). The indirect or long-term effects of pesticides and their metabolites seem to be of greater importance in ecological systems. Delayed expression of chronic effects may not only be in the form of abnormalities in vigor, behavior, growth, and reproduction but also in the form of some illnesses (possibly cancer).

The pesticides that pose the greatest potential hazards are those that are persistent and accumulate in the environment, those that degrade to toxic and stable metabolites, and those that are used in large quantities over broad areas for long periods of time. The organochlorine insecticides, because of their persistence and universal use, are the most studied pesticide group. In recent years, residues of these pesticides have been reported in soils, air, rainwater, dust, rivers and lakes, oceans, plants, food and feeds, and in the bodies of aquatic and terrestrial invertebrates, fish, birds, mammals, and man (20-22,33,43,44,77,85,87,89,91,93-96,110-113,130,135,162,168,171). Highest residues occur in tissues of animals near the top of the food chain, particularly, predators, carnivores, and man.

CAUSES AND CONSEQUENCES OF ECOSYSTEM CHANGES RELATED TO PESTICIDES

Pesticides are used in agriculture because they exhibit some degree of toxicity to specific groups of weeds, insects, and plant pathogens. However, there is continuing concern that they may also adversely affect various nonpest organisms in the environment. Pesticides are designed to control about 2,000 pest species and the estimated 200,000 nontarget species in the United States respond in diverse ways to the toxicity of these chemicals.

Some pesticides, because of their persistence in and/or repeated application on agricultural lands may accumulate and their residues are subject to dispersal to various compartments of the ecosystem. Residues may reach aquatic environments through drift during aerial application, runoff from agricultural land, and atmospheric fallout of pesticide vapors. This section examines the ecological effects of pesticides on nontarget organisms, particularly those ecological changes that are related to the productivity of land or environment services such as support of wildlife populations and maintenance of water quality.

Pesticides and Soil Microorganisms

Serious disturbance of microbial activity in soil by persistent pesticides could have adverse effects on soil fertility. Nitrogen transformations, nitrogen fixation and organic matter decomposition are important biochemical processes that could be affected. A great deal of research has been carried out, particularly under laboratory conditions, on the effects of pesticides on soil microorganisms. Excellent reviews on this subject (3,19,55,62,63,103,107,118) have summarized the effects of different pesticides on the types, numbers, and activities of microorganisms relative to various aspects of soil fertility, plant growth and development, and plant pathological relationships. Responses have been characterized as none or negligible, direct or indirect, stimulatory or inhibitory, specific or nonspecific, and temporary or lasting, depending on the pesticide's chemical properties, concentration, and mode of application, soil properties, and climatic factors. No catastrophic or even serious effects are described.

Effects on nitrification and ammonification

Ammonification and nitrification are integral portions of the nitrogen cycle mediated by soil microorganisms. The former involves the transformation of nitrogen bound in organic materials to ammonium and the latter is the conversion (oxidation) of ammonium to nitrate. Most plants utilize ammonium and nitrate for their normal growth. However, accumulation of large concentrations of ammonium due to inhibition of nitrification may cause phytotoxicity. Martin (103) cited several types of associated phytotoxicity: 1. an external toxicity to plant roots above pH 7.5 from undissociated NH_3, and 2. an internal toxicity caused by excessive absorption of ammonium. In addition, excessive ammonium in aquatic environments is detrimental to fish (133,159).

Herbicides--Parr (118) and Greaves et al. (55) reviewed the effects of herbicides on nitrification. Results indicate that while some herbicides have shown little or no effect when applied at recommended rates, others reportedly have caused marked inhibition for extended periods. For example, certain phenylurea herbicides produce no measurable effect on the conversion of ammonium to nitrate at recommended rates (2.5 to 5 ppm); even up to 40 ppm for monuron. When amitrole; 2,3,6-TBA; 2,4-DB; and diallate were applied to soil at normal field rates nitrification was inhibited for at least 8 weeks. CDEA suppressed nitrification at rates normally used in the field (3 ppm), whereas, 2,4-D at similar rates was less inhibitory. Several herbicides--propanil, 2,3,6-TBA, picloram, paraquat, and dichlobenil--at concentrations ranging from 50 to 1000 ppm showed a decreasing inhibition of ammonium oxidation. Propanil has the most inhibitory effect while dichlobenil the least. The benzonitriles, bromoxynil and ioxynil, are effective inhibitors of nitrification, whereas dichlobenil, a similar compound chlorinated in the 2,6-positions rather than the 3,6-positions and lacking a hydroxyl group, are less effective. With the exception of paraquat, all herbicides tended to decrease in toxicity over a 4-week period which indicated their degradation and loss of bioactivity. The degradation products of some herbicides, for example, propanil and diuron were found to be inhibitory to nitrification. This might explain the extended toxicity of propanil and delayed toxicity of diuron.

The effects of the triazine herbicides, include atrazine--the leading herbicides used for weed control in the United States--on nitrifying bacteria are contradictory (79). Some investigators observed increased levels of nitrate, while others reported inhibition. These contradictions stem from the differences in soil properties; *Nitrobacter*, a sensitive species to the herbicides are inhibited mainly in poor, sandy soils and with high dosages of herbicides, while soils rich in organic matter protect them due to adsorption of the herbicide; the stimulations observed have yet to be explained.

Insecticides--The effects of various insecticides, particularly the persistent organochlorines, on specific groups of soil microorganisms, including nitrifiers, have been reviewed by Alexander (3) and Helling et al. (62). They concluded that rather excessive quantities would be required to exert inhibitory effects of great consequence; however, because of the persistent nature of the pesticides, certain alterations in the soil microflora might be maintained for extended periods. Because organophosphate insecticides are being substituted for the organochlorines wherever possible, their effects on nitrogen transformations is of great interest.

Organophosphates like diazinon, Dursban®, and Zinophos applied to sandy loam soil at 10 and 100 ppm depressed the numbers of fungi and bacteria for the first 1 or 2 weeks of incubation, followed by a rapid return to pretreatment levels. In all cases there was a slight depression of nitrification and a concomitant increase in ammonium production indicating that although nitrifiers are quite sensitive to these compounds, ammonifiers are not. The minimal effects of organophosphate insecticides on nitrification is probably related to their rapid degradation in soil.

Fungicides--Fungicides and fumigants are normally applied to soils at higher rates, to kill microbial pathogens; thus they may have a greater initial and longer lasting effect on nitrification than other pesticides. Investigations on this aspect were reviewed by Parr (118). Many workers observed that the older, frequently used fungicides and fumigants (Telone®, Vapam®, nabam, dazomet) serve as partial soil sterilants and as such can effectively suppress or inhibit the nitrification process for extended periods. These chemicals at rates of 50 to 150 ppm completely suppressed nitrification for a month; this effect decreased after 60 days and nitrifying activity had recovered to 50% of that of the untreated soil.

Investigations on the effects of some new fungicides (Lanstan®, Chemagro 2653, Botran®, PCNB, TCNB, Dyrene®, maneb) on ammonification and nitrification at soil concentrations ranging from 10 to 1000 ppm showed varied degrees of inhibition. All compounds exerted partial or complete inhibitions on the nitrification process; PNCB and TCNB had slight inhibition even at 1000 ppm, suggesting that a decrease in the number of chlorine atoms on the benzene ring and the introduction of an amino or additional nitro group increased the toxicity of these substituted nitrobenzene fungicides to the nitrifying bacteria. Maneb was considerably more inhibitory than was Dyrene®, and its effect persisted even after its apparent degradation. Ammonification, or nitrogen mineralization, is generally observed to be less sensitive to fungicides than nitrification. Often the ammonifying activity of the heterotrophic bacteria, actinomycetes, and resistant saprophytic fungi is not affected.

Effects on nitrogen fixation

Symbiotic nitrogen fixation--The rhizobia are a highly specialized group of soil bacteria which play an important role in nitrogen nutrition of plants. Studies summarized by Parr (118) and Greaves et al. (55) have shown that several herbicides (2,4-D, alachlor, nitralin, trifluralin, amiben, 2,4-DB) applied at normal field rates did not affect the growth and survival of rhizobia in soil. The principal danger of herbicides to the leguminous plant-rhizobia relationship is the action on the host plant rather than on the rhizobia.

The triazine herbicides did not show any adverse effect on the *Rhizobium*; in some cases triazines appeared favorable to the bacteria by indirectly stimulating the growth of the leguminous plant. Leguminous plants following corn may have decreased nodulation due to the phytotoxic effect of the residue of triazines, particularly atrazine.

Organochlorine insecticides at normal field rates have generally not proven inhibitory to the growth and activity of the rhizobia (62). Soil fungicides and fumigants are probably more toxic to rhizobia than the other pesticides. Suppression of nodulation were observed upon application of chloropicrin, dazomet, and D-D® without adverse effects on plant growth.

However, due to the widespread agricultural practice of legume seed inoculation, it is unlikely that adverse effects of fungicides on soil rhizobia will cause insurmountable problems (118).

Non-symbiotic nitrogen fixation--The *Azotobacter* and *Clostridium* are free-living soil bacteria capable of fixing nitrogen. Effects of herbicides are either stimulatory or inhibitory (55,79). It has been shown that the triazines and 2,4-D may decrease the activity of *Azotobacter*; in other studies the activity of *Azotobacter* and *Clostridium* can be stimulated by these herbicides.

The agronomic significance of algae in the soil has not been determined precisely but algae certainly play a significant role in the carbon and nitrogen cycles. The influence of pesticides on soil algae has been reviewed (19,107). It is clear from the studies reported that of the pesticides, the herbicides pose a greater danger since they are inhibitors of photosynthesis and consequently affect the nitrogen-fixing activity of the blue-green algae.

Effects on organic matter decomposition

Organic matter decomposition is one of the most important processes occurring in soils. Any major change in its rate and extent can cause marked practical problems for agriculture, since organic matter is important for soil tilth, moisture and trace mineral retention, buffering capacity, and other fertility factors. Investigation on the effect of pesticides on organic matter decomposition has not received much consideration (55). As yet little is known about the interaction of pesticides and organic matter decomposition. Because of the increasing practice of minimum tillage more attention should be paid to the side effects of pesticides on organic matter breakdown.

Pesticides and Soil Invertebrates

Numerous soil invertebrates which are a major source of food for many species of mammals and birds could be affected by pesticides in a variety of ways. There have been comprehensive reviews on the effects of pesticides on the soil fauna (43,44,147,148). One of the most important species in terms of agronomic consideration is the earthworm.

Earthworms promote and maintain soil structure and fertility, so it is important that they should not be killed by pesticides. Fortunately, not many pesticides are toxic to these invertebrates at doses normally applied (9,40,157). Many organochlorine and organophosphate insecticides show little or no toxic effect on earthworms (cf. 9) but the carbamates and fumigants are very toxic. There has been only one report on toxic effects of herbicides on earthworms (46). Earthworms are more abundant in orchards and rangelands than in arable (cultivated) land; larger numbers of earthworms are encountered under no-till cultivation, despite higher pesticide use (40,157).

The soil flora and fauna together return organic matter to the soil and maintain the carbon cycle. If these organisms are seriously disrupted then soil structure and fertility will be affected. Although no instances where soil fertility has been seriously affected by applications of pesticides are recorded, some studies in orchards have indicated that use of pesticides may have affected soil structure because leaves on the soil surface remained undecomposed when earthworms were killed by insecticides (148).

Pesticides and Aquatic Systems

Pesticides and aquatic microorganisms and phytoplankton

Increasing concern is being expressed about the effects of agricultural use of pesticides on aquatic environments. Although the amounts of pesticide reaching aquatic systems are low-level residues, contamination is continual as a result of atmospheric transport and the perpetual processes of runoff and erosion occurring from adjacent agricultural watersheds. High concentrations of pesticides may reach waterbodies through drift during aerial spraying.

Many microorganisms found in soil also occur in freshwater, brackish, and marine environments. However, less nutrients per unit mass are present in water, and water has less biochemical activity, and a more rapid food chain turnover. Aquatic environments also contain much larger populations of algae and diatoms.

Results of some recent investigations have been reviewed (19,20,67,118, 148,163). The toxic effects of pesticides on aquatic microorganisms and phytoplankton can be delineated as 1. direct effects on growth or on specific metabolic processes such as photosynthesis, and 2. indirect effects resulting from direct and/or differential stress on certain segments of the aquatic populations. Even though a number of direct effects of different pesticides on organisms in various aquatic environments have been reported, their ecological significance is essentially unknown. Ware and Roan (163) reviewed the relative inhibitory effects of different pesticides at 1 ppm on photosynthesis (carbon fixation) of a mixed population of estuarine phytoplankton. The most toxic herbicides are the phenylureas--monuron and diuron. The toxicity of the insecticides is organochlorines > carbamates > organophosphates. The decrease in primary productivity is tantamount to reducing the food source for many fish and other aquatic organisms.

Pesticides and aquatic invertebrates

Invertebrates respond differently to varying levels and types of pesticides introduced into the aquatic environment. Effects of pesticides on aquatic invertebrates have been documented (70,87,148). Decreased numbers of some species of invertebrates due to pesticides may have important ecological effects in freshwater, especially where they include species that constitute the diet of game fish. Examples have been given in which only fish that were able to adapt to novel forms of food were able to survive in areas treated with some insecticides. Contamination of freshwater habitats with pesticides can affect not only nontarget species, but the environment itself. Sometimes vegetational changes occurred after the number of grazing invertebrates were decreased. The inbalance of invertebrate populations sometimes caused by pesticides in freshwater can indirectly modify the local flora. This, in turn, may allow increased numbers of invertebrates to occupy the area with habits and food preferences previously unsuited to the habitat. Aquatic invertebrates can accumulate pesticide residues several times greater than terrestrial invertebrates.

Pesticides and fish

The tremendous interest on the effect of low-level pesticide residues on water quality, particularly in connection with fish contamination has given rise to numerous treatises devoted to this extremely important problem including those by Johnson (77) and Holden (67). The main hazard of pesticides in aquatic environments seems to be the possibility of concentrating the pesticide through food chains so that animals in higher trophic levels acquire doses that may affect their behavior or reproductive capacity or kill them. Biomagnification seems most likely to occur in the aquatic environment because fish can take up large amounts of pesticides. They, in turn, are a major source of food for aquatic and terrestrial vertebrates including man. Marine fish-eating mammals and birds contain the largest residues of organochlorine insecticides detected (41,42). Insectivorous birds and those that consume other soil invertebrates including earthworms and slugs have lower residues in their tissues.

Pesticides and Beneficial Insects

Naturally occurring parasitic and predaceous insects control many insect pests. When plant-feeding species are severely reduced by insecticides, then parasites and predators are more severely reduced because they depend on the plant feeders for their survival (6,54,111). Following this type of disruption, population outbreaks of the plant feeders occur. Some parasitic and predaceous species are more susceptible to certain pesticides than plant feeders.

The importance of pollinating insects, particularly the bees, cannot be over-emphasized. Several agricultural crops such as vegetables, fruits and nuts, leguminous plants and cotton are either dependent on or benefit by insect pollination for proper reproduction (109). Modern U.S. agriculture is dependent on bees for crop pollination and chemicals for pest control. Unfortunately, in the U.S. pesticides annually destroy or damage about one million (20-25%) of the honey bee colonies (166). The effects of pesticides on bee pollinators have been documented (72,88,109). Differential susceptibility of bee pollinators to pesticides has been reported. The honey bee and wild bee are very susceptible to the carbamates and most organophosphates. The widespread use of these chemicals therefore may have severe effects on bee pollinators and, in turn, may reduce the pollination of agricultural crops.

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Background Paper No. 15

NEW ROOTS FOR AMERICAN AGRICULTURE

Wes Jackson
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The Land Institute
Salina, Kansas

November 1980

Office of Technology Assessment
U.S. Congress

This background paper was prepared for the assessment "Impacts of Technology on U.S. Cropland and Rangeland Productivity." The views expressed are those of the author(s) and not necessarily those of OTA.

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Wes Jackson & Marty Bender
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INTRODUCTION

Background Philosophy

Most analyses of problems in agriculture do not deal with the problem of agriculture. They talk about problems with the way farming is done (problems in agriculture), not the problems which result from tilling the soil (of agriculture). Some people warn of the domination of agribusiness, scorn corporate farming and stress the need for land reform. In response, we are now beginning to see support for the small family farm, but so far the small organizations that promote it have almost no political power. This is a problem in agriculture.

Farmers who have managed to avoid being squeezed off the land perceive the agricultural problem as one of necessary, but large and scary, capital investment coupled with a helplessness in regulating prices. Environmentalists worry about chemical farming, an extension of their traditional anxiety about industrial pollution. Neither are problems of agriculture, nor is everyone's worry about the loss of prime land to urbanization.

All the problems in agriculture are legitimate. They require thought, passion and action a hundred times greater than they now receive.

Now and then we see soil loss as a major threat. But even here, we usually fall short of bringing the entire problem into sharp focus. Rather the associated thoughts are usually directed toward some naughty farmers who are not maintaining their terraces or rotating their crops properly or, worse yet, must be plowing up and down the hill instead of on the contour. In the flat Great Plains wheat country, their counterparts are failing to leave a stubble mulch to minimize blowing dust.

Most people believe there is a right way to *do* agriculture and that failure to *do* it correctly is simply a failure in character. The very *nature of farming* itself is selfom called into question, and the ones who do question agriculture itself may be accused of wanting to return to a bow and arrow way of life.

Agriculture is seen potentially as an altogether wholesome enteprise. A color photo of a well-scrubbed, 4-H kid, clasping the rope on an equally well-scrubbed Holstein heifer at the county fair is *always* fit for an August or September calendar put out by the local feed store. One glance tells that he or she will do better on the farm. Don't the bright eyes radiate "new knowledge" and the rosy cheeks, "wholesome values?"

It isn't just through the kid at the county fair that the notion of the inherent wholesomeness of agriculture gets a boost. The appropriateness of till agriculture is firmly implanted in all civilized peoples. Saul, the first king of Isreal, was annointed in the field where he had been plowing with oxen, suggesting at least a left-handed endorsement of till agriculture from the Almighty himself. Inspired by the Biblical passage, the United Nations erected a huge statue of a man full of purpose and muscle bent to the task of beating a sword, which does evil of course, into a plowshare, which everyone knows will do good. It is worth considering, nevertheless, that the plowshare may have destroyed more options for future generations, to this point in time, than the sword. The developer of a new idea may be described as having "plowed new ground."

The major underlying assumption of this paper is that till agriculture destroys. There are places, to be sure where sustainable till agriculture is being practiced and other places where it has been in the past but these appear as small pockets scattered over the globe or as anomalies in time. So sweeping and destructive has the agricultural revolution been that, geologically speaking, it surely stands as the most significant and explosive event to appear on the face of the earth, changing the earth even faster than did the origin of life. Volcanoes erupt in small areas, and mountiain ranges require so long in their uplift that adjustments to changing conditions by the life forms are smooth and easy. But agricultural has come on the global scene so rapidly that the life-support system has not had time to adjust to the changing circumstances. In this sense, then, till agriculture is a global disease, which in a few places has been well-managed, but overall has steadily eroded the land. In some areas, such as the U.S., it is advancing at an alarming rate. Unless this disease is checked, the human race will wilt like any other crop.

A second assumption is that not only does agriculture destroy but it has been given every chance to prove itself as a viable experiment for continuously sustaining a large standing crop of humans. Its failure to do so is difficult for most of us North Americans to comprehend because since Jamestown, we have harvested more and more food. In spite of all our scientific and technological cleverness of recent decades, not one significant breakthrough has been advanced for a truly sustainable agriculture that is at once assuredly healthful and sufficiently compelling to be employed by a stable population, let alone an exploding one.

People in all sectors of agricultural production are understandably conservative or suspicious of proposed changes in the way we grow food. It is understandable for it does involve fooling with our most basic need. Therefore, when there is a call for a bio-technical fix (based on perennials), it is not surprising that some version of one or more of the following counter-responses is offered in turn.

1. In the entire array of soil conservation measures are some easily copied traditional applications which require little if any research and development.

2. The problem is a spiritual one involving stewardship. We need a stronger appeal to the old fashioned stewardship such as practiced by the Amish and Mennonite farmers.

3. Enlightened self-interest will result with more education for the farmer and he, in turn, will take the necessary measures.

4. Minimum or no-till methods will save the soils.

5. Government policy which employs both the "carrot" and "stick" approach will encourage sound soil conservation practices.

For centuries we have been aware of many soil conservation measures which, if appropriately applied, the soil loss problem would cease to exist. The problem is that many of these measures must be practiced at once and there are few farmers that will stay with these practices diligently either because they are pressed for time or the immediate economic situation causes them to forgoe some of their practices. The problem may be a spiritual one, as Wendell Berry suggests, but the reality of the situation suggests that good stewardship is practiced best by a God-fearing minority who regard farming as the highest calling. Even so, at least on Mennonite farms in Kansas, soil erosion is serious. Enlightened self-interest seldom works either. There are many examples where it doesn't pay to conserve the soil. Pimentel reports of Northeastern Illinois farmers whose conservation measures penalized them $39/acre/year.

For these first three contentions, there is a major consideration worth mentioning. It has to do with our very nature which is the result of the way we probably spent most of our evolutionary history. We usually forget or ignore that a tiny percentage of our time on earth has been devoted to intensive ecosystem management - farming. Is it any wonder that farming is so alien to us when scarcely 5 percent of our evolutionary history with the big brain, 10,000 of the last 200,000 years, has been devoted to agriculture?

The balance of this time and extending backward another couple of million years or so, we took from nature by hunting and gathering, probably gathering more than hunting. What is important is that we took without thought for the morrow. The concepts of leisure and work likely did not exist. If life in this past was like what we find in primitive tribes today, sustenance and health was managed in a work week that was scarcely half that of current industralized societies.

When agriculture came onto the scene, when *we took more control* of our provision, we had to be concerned about our livelihood, not just for the day, but over the period of an entire year. As populations increased, the successful ones were those who thought ahead, probably as much as a year or more. Recall the Biblical Joseph's recommendation for a seven year grain storage program for the Egyptians. When we think of it, this most have involved a tremendous stretch of our paleolithic predispositions tuned more to the moment than to the year. What is even more amazing is that the problems which confront us now---and we elaborate here because the soil loss problem is among them---do not involve one to seven days or even one to seven years but one to seven *decades* and more. The difference between one day and one decade of days is a jump of three orders of magnitude. We should not be so surprised at our strong propensity to discount such a "distant" future. The first three considerations mentioned earlier all involve taking action in order to avoid problems certain to develop from 10 years to half a century down the line---when most of us are gone.

The fourth consideration, the one pertaining to minimum or no-till methods and the reliance on the application of chemicals is of crucial concern here. We are not concerned that these are fossil oil-based, for the total annual application of herbicide and insecticide amounts to less than .04% of our 1980 oil consumption. Furthermore, we do not hinge our argument or concern about chemicals on the fact that these methods invite changes in the weed flora and eventually a decreased effectiveness of the herbicide. We believe there is a much deeper problem which the scientific community needs to face. It is a philosophical problem and has to do with the way we perceive ourselves in relation to the environment.

Western civilization carries a religious legacy, however unwitting, however secularized, it has religious roots. This is the notion that the environment is "out there". Part of that legacy at least is rooted in the Genesis myth of the Creation in which all life forms were created almost at once, except humans. After this creation, God paused and then invented us. It is a two-stage creation myth. What molecular biology has given us, on the other hand, is the powerful evidence that we are of one creation, for all of us---redwood, whale, sunflower, osprey, human---consist of the same 20 amino acids. All life forms, furthermore, with a few unimportant exceptions, consist of the same four nucleic acid bases.

The implication of these relatively recent findings is that a willful pollution of the environment is potentially a willful pollution of ourselves. It is not chemistry which should scare us, for nature provides an amazing array of chemical protectors for this organism and that. The first question is whether we are introducing a chemical into the environment with which our cells have had no evolutionary experience. Secondly, if we are introducing a chemical that has been around over the eons, is it being introduced at a level beyond the evolutionary experience of our cells? This is not to say that every chemical with which our cells have had no evolutionary experience is automatically a danger. Some human-devised chemicals may be structurally close enough that our cells can deal with them. We should remember also that there are some ancient chemicals around which are lethal or damaging. They are either so toxic our cells haven't had a chance to deal with them or they are such infrequent confronters they haven't been worth fooling with in terms of our genetic response.

Once all the exceptions have been acknowledged, we at last conclude that ours is a philosophical stance that we have assumed to be necessarily prudent before we allow nature's life forms to become guinea pigs more than ever. It isn't just nature "out there" that would be the guinea pig in this empirical experiment, it is we ourselves as part of nature.

Finally, "carrot" and "stick" approaches have long been a part of government policy through such vehicles as the various cost-sharing programs for farmers who participate in some SCS or ASCS program. They may have contributed to a slowing of soil loss, but soil still runs to the sea.

In summary, we are promoting research into high-yielding perennial grain crops which grow in mixtures and the eventual curtailing of annual monoculture because:

1. Stewardship has failed except in a few places in the world.
2. Enlightened self-interest appeal assumes the economic system is sensitive to long-term considerations when in fact it is not. Part of the personality of inflation and high interest rates is that more and more of the future is discounted.
3. The array of soil conservation measures may be large, but the extra thought and effort necessary to make them effective has not been, and probably won't be, very compelling.
4. No - or minimum - tillage, besides having other serious flaws, is chemical-dependent and highly suspect.
5. A reward and punishment system imposed on farmers sufficiently powerful to take up the slack of an economic system almost totally insensitive to ecological necessity is probably unworkable.

Perhaps most of the failures in agriculture involve the failure of humans to force themselves into alien activity. When we were gatherers and hunters what one might call appropriate management of ourselves must have been unnecessary - it naturally flowed. The successful development of herbaceous perennial seed-producing polycultures allows for a re-establishment of a vegetative structure similar to the vegetative structures which existed before an area was first tilled and is therefore a good beginning for rehealing the long discussed split between humans and nature.

Even when we do think deeply about the problem, we are inclined to accept the eventual decline of agriculture as being in the nature of what the noted philosopher Alfred North Whitehead called the essence of dramatic tragedy - inevitable.

In The Unsettling of America,[1] Wendell Berry raises our sights on the agricultural problem by dealing with most of the problems in agriculture. Berry sees that the problem basically comes from a failure of the human spirit. There is a religious dimension to the agricultural problem which needs addressed and there is a profound need for all of us to examine the advisibility of regarding the farm as a food factory rather than as a hearth. After an examination of the many areas in which humans have failed over the centuries to adequately deal with the agricultural problem, we think agriculture needs this bio-technical fix described here. We are not entirely comfortable with such a proposal, --- not because we don't believe in its promise, but because of what technical fixes promote even if they are of a "bio" variety. They feed the modern day zealot who sees all of our problems to be materially or technically solvable. Such an attitude prevents us from facing up to the deeper moral and spiritual problems Berry so eloquently considers. Nevertheless, it is the bio-technical fix we will discuss here for Berry's important topic is outside our scope.

Three Major Considerations of the Argument

The argument presented here involves three basic considerations. (1) We believe there is a need for a future agriculture based on herbaceous perennial polycultures where the desired product is grain or seed. (2) These perennial mixtures of the future would likely be derived from plants now regarded as possessing little promise for meeting human needs or demands.

(3) Because of advances in biology over the last half-century, we believe the scientific-technological community has the know-how to develop a truly sustainable agriculture.

The Need for Herbaceous Perennial Seed-producing Polycultures. We believe such a bio-technical fix would make it easier for humans to solve many problems in agriculture at once. But in a less speculative view there are two major reasons why there is a need for such an agriculture. First of all, we need to think very hard about meeting the needs of the land if unborn generations are to inherit a chance to live healthful and productive lives. Right now, our agricultural lands are experiencing severe soil loss nation-wide. The Soil Conservation Service recently set the average of five tons of lost soil per acre each year,[2] but the 1977 General Accounting Office study indicates we are losing over 15 tons an acre.[3] An engineering approach to soil conservation has failed to adequately prevent soil loss. The biological approaches of strip cropping and rotation have not been sufficiently compelling for widespread application and even where tried have been poor substitutes for nature's incomparably more effective means of soil retention.

The second major reason as to why we need such an agriculture is energy-related. Our current high production is managed by excessively high increases in fossil fuels, particularly the portable liquid fuels. The energy crisis is most acute due to the scarcity of the portable liquid segment of global fossil fuel reserves. It may be that it is within the area of agriculture that our current energy path is most "hard." A "soft" agricultural path is at least as necessary as a "soft energy path."[4] If we are to feed people in an oil-less future at anywhere near our current level of grain consumption, an agriculture many times more energy efficient than our present one will be necessary. Such an agriculture offers promise for huge fossil fuel savings for it would rely more on dispersed solar energy to do jobs managed by an array of life forms at low thermal levels, jobs the agriculturist pays to have done by fossil fuel units at high thermal levels.

In the long run soil and water are more important than oil. We currently have a cushion or a time period of perhaps 50 years to make the transition from oil back to soil and an agriculture which includes a sound water management policy.

New Crops from Wild Species. The second major contention that these perennial mixtures of the future will likely be derived from plants now regarded as possessing little promise for meeting human needs or demands, needs some elaboration. Essentially all of our high-yielding grain crops are annuals and where they are not, as in the case of the sorghums, they are treated as such. There has been extensive research to develop perennial wheats and yet not a single strain has been sufficiently compelling to be successful on the market. The introduction of perennial germ plasm into crops in which the annual condition is well-fixed will likely be disappointing simply because thousands of plant generations have passed in which we humans worked on the annual theme.

It is not just the annual condition for which the genes of our major crops are tuned; they are also tuned, particularly in the temperate regions, to exist as a part of a monoculture. Even under conditions which are technically referred to as following under the umbrella of polyculture, many of these plants are in rows or strips not mixed or dispersed as are the wild and "useless" plants in nature's array.

It seems to make more sense, therefore, for us to begin with plants whose genetic ensembles have been tuned to getting along with other species in a living community but which at the same time show promise for meeting some of the human-defined needs. It seems more sensible to start with the complexity which nature presents us and keep track of what we lose in our selection program than to impose a wide array of unknowns on high-yielding crop species which have long since lost the systems necessary, not just to survive, but to contribute to a polyculture.

Agricultural Science and Technology Can Do It. Finally we come to our third pre-supposition which holds that the scientific-technological community possesses the know-how to make this agricultural revolution possible. Since the work of Gregor Mendel was rediscovered in the first year of this century, an enormous amount of scientific knowledge and technical skill has developed, much of which has already been applied to yield increases in agriculture. But there is an even greater wealth of knowledge and skill which has accumulated as scientists sought to relate Darwin's theory of evolution to Mendel's elements of heredity. Dozens of investigators put their imaginations and equipment to the task of proving or disproving the chromosome theory of heredity. Later, classical taxonomists used these new tools and the new knowledge to modernize their thinking about relationships within plant and animal groups and routinely make numerous wide crosses. Chromosomes were counted, artificially doubled and redoubled again. Chromosomes were introduced and taken away. The chromosomal gymnastics which preceded sex cell formation were observed and recorded. Most of this basic research was not used for the improvement of major crops. Most crop improvement came with the invention of and explosion within the field of statistics through the efforts of R. A. Fisher and his disciples. Here the emphasis was on analysis and the fine-tuning of the plants and animals which were already proven. Nevertheless, there is a reservoir of knowledge, much of it largely forgotten since the era of biochemical genetics introduced in the 1940's. And though much of this knowledge and technology has cooled and been forgotten, it's in the literature and available for resurrection.

THE BIO-TECHNOLOGY

Some Definitions and Relevant Investigations

By herbaceous, we mean non-woody plants as opposed to trees or shrubs. A perennial is a plant that lives three or more years on its own, sending forth shoots each spring from root or rhizomes. It is not to be confused with a biennial which develops a rosette one year and one or more reproductive stalks the next. The annual grows from seed, flowers, sets seed, and dies all within a single year. There are some perennial plants which are basically tropical which we treat as annuals in temperate regions; the best known examples being cotton and sorghum. We would designate them as perennials treated like annuals in regions where the roots winter-kill. We suggest this distinction because there may be an outside chance that one day genes for cold resistance could be gradually introduced into such a plant and make it a functional perennial in temperate regions.

Range grasses produce seed. So when we emphasize seed-producing perennials our interest is in the seed, or more accurately, caryopsis or fruit, in the case of the grasses. Our interest here is not in the forage.

Finally, the expression polyculture is a general term which can be most confusing. Kass[5] has organized the numerous terms into a convient taxonomy. A polyculture can mean simply growing more than one crop on the same land in one year (multiple cropping). It can mean growing two or more crops simultaneously in alternate rows in the same field in a year (intercropping). Relay planting is a form of polyculture in which the maturing annual crop is interplanted with seedlings or seeds of the following crop. If the flowering period of one crop overlaps that of the second crop in the field then this is inter-cropping or according to some, relay inter-cropping. Interplanting is where long-term annual or biennial crops are interplanted with short-term annual crops during early stages of plant development. When arable crops are grown under perennial crops it is called interculture. Finally, there is mixed cropping where two or more crops are grown simultaneously and intermingled with no row arrangement. It is this latter condition which we will emphasize here.

There are numerous terms associated with various combinations. What we have in mind when we say polyculture in this paper, is what many would call mixed cropping; i.e. where two or more species are intermingled simultaneously. Where such a mix is planted in rows, we would designate it as a row polyculture.

In the review and analysis of polyculture cropping systems mentioned earlier, Kass considered only the annual crops. He gave three reasons for excluding perennials, one of which is relevant here. Kass asserted that "principles obtained from the study of perennial or pasture species are probably not applicable to annual crops, which are often biologically completely dissimilar." This important statement deserves special scrutiny in order to determine just how biologically dissimilar perennials and annuals are and what the implications of those special dissimilarities might be. But before we consider this biological dissimilarity, we want to examine Kass' general conclusions and recommendations about annual monoculture.

Kass' literature review generally indicates that polyculture is beneficial, especially if there is a good choice of crops in conjunction with other environmental variables. The right mix in the specific situation seems critical. We see no reason why this would probably not be true of perennial polycultures as well. He further concluded that:

> "In terms of withdrawal of nutrients from the soil, economic return, improvement of the nitrogen status of the soil-plant system when one of the crops is a legume and greater stablilty of yields over time, the benefits of polyculture are clear."

The main area of concern, which is quite important for our purposes has to do with the ease of harvest and other mechanized operations. We can easily imagine this to be true given some of the traditional mixes of annuals in polyculture, such as corn and beans.

We would anticipate fewer problems with the kind of perennial polycultures we anticipate for we would expect that species would set seed either once or twice during the year with all species of a particular season maturing in synchrony. It would be more like harvesting a mixed pasture. Though the machinery is not invented for such harvest, it seems to be a minor problem for the agricultural engineer. Seed separation should present no major problem.

Professor Jack R. Harlan at the University of Illinois has commented that "the general principles that apply to the dynamics of natural grasslands apply just as well to the dynamic balance of species in tame pastures."[6] We would expect this to be true for herbaceous perennial polycultures in which the seed products are emphasized. Harlan describes two of the most popular pasture mixtures in the U.S.; orchardgrass (Dactylis glomerata) with ladino clover (Trifolium repens) and smooth bromegrass (Bromus inermis) with alfalfa (Medicago sativa). In any management practice, the main objective is to maintain a reasonable balance between the grass and the legume, Harlan points out, in order to secure near maximum yields with the least expense all around. The nutrient needs of ladino clover are different than the nutrient needs for the grass which requires high levels of nitrogen. For the clover-orchardgrass mix, Harlan concludes "management requires close observation and attention to detail, (and) many farmers have been able to maintain a good balance for years on end."

On the other hand in the brome-alfalfa mixture, there are other ecological requirements for the two species. One is a warm-season legume and the other a cool-season grass. The farmer can favor the legume by heavy grazing early in the season or favor the grass by nitrogen application or heavy grazing in summer. "The control of composition depends more on timing than on degree of use."

These are two positive notes about management of mixtures. There are, of course, problems as well which must be overcome. There will be problems such as competition; too vigorous a growth for some seedlings to compete well, but all in all, most of the problems of managing a polyculture seem manageable without undue presence of the experts.

Yields of Some Select Perennials

The incentive to develop high seed yield in perennials has been small compared to the effort which has gone into the development of high yield in annuals. The handful of our nation's native seed merchants have probably had more reason than most to increase yield but even for them a modest increase in germination has been more important than a yield increase. The USDA regional plant materials centers has likewise had reason to increase the yield of the various perennials and they have with several species. But they have little time to devote to such work for they are terribly understaffed, considering that their mission has been to supply seed for the thousands of Soil Conservation Districts. The range agronomists have understandably paid close attention to _forage_ yield increase with only a minor amount of effort devoted to seed-yield improvement. To date, there has been nothing close to what one might consider an aggressive national program for perennial seed yield increase.

Review of herbaceous perennial seed yields. The question of whether we can breed high-yielding perennial grain crops encounters the basic biological question of whether perennialism and high seed yield are mutually exclusive or not. Part of the answer depends upon a definition of what we mean by "high." Since winter wheat is regarded as a high yielding crop, we have assumed that a yield of 1800 pounds per acre (30 bushels at 60 pounds/bushel) would be our arbitrary standard and that we would make adjustments for protein, carbohydrates and oil yields on a per acre basis later.

We have surveyed the literature on herbaceous perennial yield and have summarized it in the following six categories represented in tables 1 through 6. These categories are: (1) irrigated grass yields, (2) dryland grass yields, (3) irrigated native grass yields, (4) dryland native grass yields, (5) irrigated legume yields, and (6) irrigated composite yields. The field condition for each yield listed is presented as reported in the literature. Unless specified under the field condition as representing a specific year, each yield is the upper limit of the range of yields recorded over many years. It is assumed that all the species were cultivated in rows, except buffalo grass (Buchloe dactyloides).

In Table 1, we see that Buchloe dactyloides had a yield of 1,727 lbs/acre in the 4th year. The four-year average for that particular crop was 1,304 lbs/acre. Although these yields include the burs, of which the seeds are a small part, the yields do represent fruit/seed material, which incidentally, is also the case of our cereals. If we go down the list, we see that Sporobolus cryptandrus yields 1,000 lbs/acre, of which essentially all is grain. Sporobolus cryptandrus, (Table 2), which is a warm season grass, has an exceptionally high yield, compared to the other grasses which are all cool-season.

Tables 3 and 4 are presented to show the record of native grasses because Tables 1 and 2 consist mostly of introduced grasses. We need to consider the native grasses because it may be easier to develop them into high yielding perennials in a prairie climate than the introduced grasses, though this is by no means a foregone conclusion for most of our high yield crops originated elsewhere.

Although Tables 5 and 6 present some promising legumes and composites, the seed yields of only a small percentage of the species in these two families and in other families not considered in this paper have been recorded in the literature.

It is also instructive to look not only at the seed yields, but also the protein yields of these perennials. Table 7 compares the per acre protein yields of three annual crops, corn, wheat, and soybeans, with some of the perennial species presented earlier. The protein yield of wheat is already surpassed by some of the perennials in Table 7.

Table 1. Irrigated Grass Yields

Species	Seed Yields (lbs/acre)	Field Conditions	Reference
Buchloe dactyloides[7]	1,727*	60 lbs N, 60 lbs P 4th year	7
Festuca arundinacea[8]	1,460	fertilized, 40 acres	8
Dactylis glomerata[9]	1,100	Great Britain	9
Eragrostis curvula[10]	1,100	fertilized	10
Sporobolus cryptandrus[11]	1,000	---------------	11
Elymus canadensis[12]	1,000	fertile soil	12
Agropyron cristatum[13]	996	fertilized, 2nd year	13
Bromus inermis[13]	942	fertilized, 1st year	13
Lolium perenne[13]	930	32,000 acre average 1 year	13
Lolium multiflorum[13]	930	110,000 acre average 1 year	13

* Includes the burs.

Table 2. Dryland Grass Yields

Species	Seed Yields (lbs/acre)	Field Conditions	Reference
Sporobolus cryptandrus [14]	900	native stand Hays, KS	14
Bromus inermis [12]	500	fertile soil	12
Agropyron trichopherum [15]	500	70 lbs N	15
Agropyron intermedium [12]	450	fertile soil	12
Festuca arundinacea [12]	400	fertile soil	12
Agropyron trachycaulum [15]	400	70 lbs N	15
Stipa viridula [12]	400	fertile soil	12
Agropyron elongatum [15]	400	70 lbs N	15
Agropyron spicatum [15]	400	70 lbs N	15
Elymus junceus [12]	300	fertile soil	12

Table 3. Irrigated Native Grass Yields

Species	Seed Yields (lbs/acre)	Field Conditions	Reference
Buchloe dactyloides [7]	1,727*	60 lbs N, 60 lbs P 4th year	7
Elymus canadensis [12]	1,000	fertile soil	12
Sporobolus cryptandrus [11]	1,000	--------------	11
Bromus marginatus [16]	902	30 lbs N, 1st year	16
Panicum virgatum [12]	600	fertile soil	12
Eragrostis trichoides [12]	500	fertile soil	12
Agropyron smithii [12]	500	fertile soil	12
Bouteloua curtipendula [12]	500	fertile soil	12
Sorghastrum nutans [12]	500	fertile soil	12
Bouteloua gracilis [12]	500	fertile soil	12

* Includes the burs.

Table 4. Dryland Native Grass Yields

Species	Seed Yields (lbs/acre)	Field Conditions	Reference
Sporobolus cryptandrus[14]	900	native stand Hays, KS.	14
Stipa viridula[12]	400	fertile soil	12
Sorghastrum nutans[12]	300	fertile soil	12
Bouteloua curtipendula[12]	300	fertile soil	12
Eragrostis trichoides[12]	250	fertile soil	12
Panicum virgatum[12]	250	fertile soil	12
Elymus canadensis[12]	200	fertile soil	12
Orzopsis hymenoides[15]	200	70 lbs N	15
Agropyron smithii[12]	200	fertile soil	12
Andropogon gerardi[12]	200	fertile soil	12

Table 5. Irrigated Legume Yields

Species	Seed Yields (lbs/acre)	Field Conditions	Reference
Desmanthus illinoensis[17]	1,189	5-year average	17
Astragalus cicer[18]	1,000	fertilized	18
Onobrychis viciaefolia[15]	1,000	70 lbs N	15
Medicago sativa[15]	500	70 lbs N	15
Trifolium pratense[13]	500	70 lbs N	13
Lotus corniculatus[15]	500	70 lbs N	15
Trifolium hybridum[13]	425	4,200 acre average 1 year	13
Vicia villosa[13]	400	26,000 acre average 1 year	13

Table 6. Irrigated Composite Yields

Species	Seed Yields (lbs/acre)	Field Conditions	Reference
Ratibida pinnata [19]	1,600	--------	19
Helianthus maximilliani [20]	1,300	0.01 acre	20
Liatris asper [21]	550	0.01 acre	21
Liatris pycnostachya [22]	435	--------	22
Engelmannia pinnatifida [17]	409	--------	17

Table 7. Seed Protein Yields

Species	Seed Yield[23] (lbs/acre)	Protein[24,25]	Protein Yield (lbs/acre)
Annuals			
Corn	5,680 (100.8 bu)	9	511
Wheat	1,896 (31.6 bu)	12	228
Soybeans	1,770 (29.5 bu)	42	743
Perennials			
Dactylis glomerata	1,100	27	297
Elymus canadensis	1,000	27	270
Bromus inermis	942	19	179
Festuca arundinacea	1,490	22	321
Desmanthus illinoensis	1,189	34	404
Astragalus cicer	1,000	40	400
Onobrychis viciaefolia	1,000	40	400
Medicago sativa	500	37	185

Suggestions. There is a need for standardizing seed yield data. With each published yield should be listed the specific or average rainfall and irrigation, seed purity, plot size, kind and amount of fertilizer, and whether the plants were in rows or solid stands.

More data on perennial seed yields needs to be collected as there may be perennials not now known to be of high yield potential. For example, almost all grass seed yields are from grasses ordinarily used for forage and hay. Such grasses have been selected to send much of their energy to the leaves rather than to the seed. Perhaps there are perennial grasses that are poor for forage but good for seed yield that have not been studied, such as the dropseed genus Sporobolus.

The direction of future perennial grain crop research may depend on the results of research yet to be done, which could determine which perennials should be grown in rows and which ones in solid stands. Since soil erosion is our main motivation for doing and promoting perennial grain crop research, erosion studies need to be conducted to determine the relative ability of perennials in rows vs. stands to reduce soil loss. Although rows have higher seed yields than solid stands due to tillering, it may turn out that rows of perennials do not reduce soil erosion to a sustainable level. In that case, seed yields of perennials in solid stands will need to be recorded in order to find candidates for grain crop research.

Prospects for Yield Improvement

Ordinary breeding. Compared to the extensive breeding work with annual crops, the selection program to improve seed yield of herbaceous perennials is practically nil. We feel confident that long before we have matched the vigorous effort of those who have improved our annual crops, that dramatic gains will already have resulted. These gains might be expected to come from the same sources breeders have historically called upon to increase yield, by re-allocating the resources within the plant and by increasing plant performance overall.

The problem of re-allocating the resources within a perennial requires that we pay attention to the problem of robbing too much energy from root storage. With a C_4 perennial grass, for example, energy is transported to the underground parts late in the growing season to help the plant overwinter and be ready to send forth leaves and stem material the following spring.

Redmann, Maxwell and Reekie[26] at the University of Saskatchewan note that a comparison of the carbon budgets of several grass species show that both annual and perennial cultivated grass species divide their gross photosynthesis about evenly between respiration and production. However, both cultivated and native perennial grasses devote a larger proportion of their photosynthate to maintenance and root respiration and a lower proportion to growth and shoot respiration, when compared with annual grasses.

More dramatic results are likely to come from changing a plant or developing one which has an overall increase in vigor - such as what breeders did to corn or Zea mays. During the 1920's, corn yielded around 30 bushels per acre. The 1979 crop averaged 106 bushels per acre;[27] more than a threefold increase. Clearly the increase was not entirely due to a complete redesign of the corn plant which re-allocated its resources from within, but rather there must have been an overall gain in the plant, backed of course by ever increasing doses of fossil fuel based fertilizer and pesticides. It seems that perennialism need not suffer much as we begin to select for higher yields and that the old plant breeding principles can be applied with impunity.

Wide crosses. Verne Grant, in his well-known book Plant Speciation,[28] reports on his survey of the literature of 72 plant groups. Some were genera; others sections or subtribes. Among his numerous efforts at synthesis, Grant classified these taxa based on the presence or absence of breeding barriers between related species, whether they be incompatability (as for example, one plant not accepting the pollen of another) or sterility barriers (the gametes may be unbalanced chromosomally). The results of this tabulation are important and encouraging. Closely-related annuals are often separated by incompatability barriers but both woody plants and perennial herbs usually cross freely with close relatives. Moreover, after the hybrid has been made, the hybrid itself is much more likely to be fertile if it is a perennial than if it is an annual. Numerous papers by independent investigators and reviewers, in particular Darlington,[29,30] and Stebbins[31] confirm these conclusions.

There was sufficient literature for Grant to compare different sections of the same genus in two different families, a particularly important consideration, for the conclusions suggest that a general biological principle may be at work in our favor. In Helianthus, the sunflower genus, is the perennial complex of H. giganteus, a complex which is infertile. Conversely, the annual species of the H. annuus complex is intersterile. The perennial species of Lepidoseris are mostly interfertile while in Crepis (Compositae) three sections of annuals have a preponderance of intersterile crosses.

Perennials, according to Grant, mostly outcross whereas most annual groups are partially or predominantly self-fertilizing species. As the breeder works to maximize yield, he or she must decide whether to emphasize fitness or flexibility. Fitness results from an emphasis on inbreeding, best accomplished by self-fertilization. Flexibility results from outcrossing. With fitness one can increase yield in a narrow environment but at the expense of increased vulnerability. A logical conclusion from the results of Grant's survey is that annuals tend to be "fit" while perennials tend to be "flexible." This is another happy situation, for genetic vulnerability to all sects of environmental limits is less likely to be a problem in the early stages of a breeding program than if the researcher was working with annuals.

The closely related interfertile perennials Grant considered are all from the north temperate zone. His generalizations, therefore, are particularly important for it means these closely related perennial species have either been ecologically isolated or have had their gene pools kept apart by factors _external_ to the plant during and since speciation. Species that are not closely related have their reproduction isolated _internally_, through gene-controlled incompatability or some other barrier which prevents viability. The implications of these generalizations for the development of perennial seed-producing crops out of wild plants is that _the internal channels of gene exchange between perennial species are mostly wide open_ even within relatively wide taxonomic limits. And though crosses beyond those limits may be closed due to the gene-controlled incompatibility or inviability barriers, many of these barriers can even be overcome with some clever immunological manipulation, embryo culture or whatever.

We have been speaking in generalities about the nature of perennials vs. annuals for these north temperate zone plant species. We are fully aware that we are not dealing with absolutes when making these distinctions. There is one main difference between annuals and perennials, however, that is a near absolute and a most fortunate circumstance for the future breeder of perennials. While annuals have employed _chromosomal_ sterility as an isolating mechanism among closely related species over time, this feature is almost absent in the perennials. Gene elimination, addition, or transfer is relatively easy so long as meiosis in sex cell formation is normal. If it were the other way around, the problems for perennial crop development would be compounded.

Induced Polyploidy. The chromosomes of over 35,000 plant species have been counted and based on the reports of these studies, it is now estimated that between a third and a half of all flowering plants[32] and 70% of the grasses[33] are polyploids. This widely established phenomenon includes many of our important cultivated plants and because of this fact, along with the additional fact that polyploidy has been an important contributor to adaptation in nature, it should be counted as potentially important in new perennial crop development.

Unfortunately, the role of polyploidy in new crop development has been disappointing to many plant scientists who had high hopes for it soon after it was discovered. Triticale stands out as the outstanding successful attempt to produce a polyploid crop but it is only marginally compelling at best. To date, the main value of polyploids produced by humans is that they have served as vehicles for transferring specific genes between chromosome races and species. This is important for our purposes here because it is a potential tool for making the very wide crosses where the chance for hybridization is closed due to gene-controlled incompatibility.

The disappointments from the failure, so far, to develop high-yielding annual polyploid crops should not over-shadow one very important fact, which is that the highest percentages of polyploidy are found in perennial herbs and the lowest in annuals.[34] In the grass family especially, there is a correlation between efficient vegetative reproduction, particularly by rhizomes or stolons, and high percentages of polyploidy. This correlation can be readily explained by the "bottleneck hypothesis" as described by the [illegible]t geneticist, Professor G. Ledyard Stebbins. According to this hypothesis, polyploids, in their early stages require favorable combinations of circumstances in order to be perpetuated. A new annual polyploid has less of an opportunity for producing offspring than a new perennial polyploid. This is because new polyploids or "raw polyploids" can be expected to have higher irregular meiosis, that is irregular chromosome pairing and segregation during sex cell formation. A polyploid perennial, unlike an annual does not have to come up with "winning combinations" in the first year, for it will appear the next. Furthermore, if it has stolons or rhizomes, it can clone itself, many times over, and if it is not sexually self-incompatible, numerous crosses can be made. Thus the lowered probability of success due to irregular meiosis in our annual polyploid becomes probable with the thousands of attempts made possible due to perennialism, asexual cloning and self-compatability. Once through the "bottleneck," the numbers of problems begin to diminish. Since the perennial is a far better candidate for getting a "raw polyploid" through the bottleneck than the annual, perennial polyploids would appear to have great promise for new crop development.

Summary. In our attempt to determine whether perennialism and high yield were mutually exclusive we discounted the woody vegetation for we recognized the unfairness of comparing trees to annuals. Trees can out-yield annuals probably because they have a greater vertical distance to draw on for capturing the sunlight which strikes a square meter. But when we stick to the herbaceous habit, the prospects for yield improvement in the perennial may ultimately be as high as for the annual. The most serious draw back may be the energy cost to maintain the root system over the winter and allocate energy for the plant to burst forth next spring. We suspect that most breeding strategies will be to increase the yield of biomass overall and then allocate more of the photosynthate to the seed. Selection and breeding for determinate flowering and seed set should contribute to increased seed harvest early on, but in the long run, increased yield will have to come from the same sources breeders have historically called upon for yield improvement.

We hope the researcher will not be discouraged at the prospect for developing new species through wide crosses and polyploidy based on the experience with annuals. The results of Grant's survey on the lack of crossing barriers between close perennial species should encourage us. So should the fact that polyploids stand a better chance of being useful to the breeder of perennials than to the breeder working with annuals.

Science and Technology By-Passed

We have considered why the plant science community has launched no major effort to develop high-yielding perennial polycultures. One obvious reason, of course, is that there was plenty of work to do just going with the proven crops. Another possible reason is that most scientists paid little attention to the relationship between perennialism and soil protection or stated negatively - the relationship between annuals and soil loss. Even if they did, they may have felt the changes necessary, whether they are scientific or institutional, were too numerous and that long-term funding could not be assured.

There are some historical considerations too, which should not be overlooked - considerations which have to do with the nature of science. Scientists naturally want to push back the frontiers of knowledge. And though there are many lateral frontiers, which many scientists wish to explore, and do in a limited way, the main arrow in genetics has pointed from establishing the chromosome theory of heredity as a fact, to modeling the DNA helix, and more recently to deciphering the genetic code for protein synthesis. Sub-fields have been ignored or mostly forgotten along the way, fields that projected promises in their hey-day.

In the 1930s the toxic alkali drug, colchicine, was discovered to double plant chromosome numbers. Artificial polyploidy became immediately possible and encouraged geneticists to be hopeful about the prospect of polyploid-induced gigantism and the associated vigor which would enhance production, particularly of such crops as sugar beets, grapes, and watermelon. Swedish scientists especially, but scientists around the world as well, did work for a while on crop improvement through polyploidy, but today, some 40 years after the discovery of the technique, the prospect for new polyploid varieties has been disappointing. This is in spite of the fact that such a large percentage of the flowering plants, including our crops, are of polyploid origin. We should remember that much of this work has been with annuals and that perhaps most of the disappointment has resulted from the lack of success in getting these annuals through the "bottleneck" discussed earlier, the "bottleneck" which scarcely exists as a liability when dealing with perennials.

In the next decade, the 1940s, radiation was viewed as an inducer of genetic variation through mutation. After World War II thousands of research papers were published on this subject and hopes were high that plant breeders had a powerful new tool at their command to increase yield and resistance. This technique did promote some good mutations but breeders soon realized they were faced with an old problem. They still had to get rid of the larger number of deletarious genes; the same problem which faced them in the pre-atomic days when they sought to introduce desirable genes from the wild relatives of our crops. The role of radiation for new crop development is seldom discussed anymore even during this period when germ plasm loss through the demise of wild genetic stocks and genetic truncation of our major crops is of concern for most geneticists.

In the next decade, quantitative genetics seemed to promise performance certain to surpass the previous results of ordinary plant breeding. Breeders did benefit from the new models but quantitative geneticists have yet to develop new varieties or germ plasms that have been adopted, though admittedly most of them probably didn't perceive new variety development as their primary mission.

Now it is the era of gene-splicing, the newest revolution, not just for genetics but for all of biology. There has been a dizzying succession of advances since Watson and Crick gave us their famous DNA model in 1953 though it took the recent debate to bring most of these successes to a publically visible level. It remains to be seen what the benefits will be beyond the impressive development of such important biological agents as insulin and interferon by recombinant DNA procedures, but if this recent technology is in the tradition of the other advances in genetics over the last 50 years, the benefits to plant science will be limited. But it need not be that way.

This history of the science of genetics causes us to consider what is probably a species problem and perhaps a problem even more characteristic of scientists and even worse for biologists. The problem is that numerous worthwhile situations - jobs, a perfectly adequate home or community are traded or walked away from for no good reason. If the ordinary citizen becomes bored with his or her situation we shouldn't be surprised if the scientist's mind becomes restless or boredom-prone shortly after the exciting discoveries which opened up a specialized discipline. What is perceived to be a stepping stone toward the next logical discipline within a field, however, is often dictated by fashion. In a broader sense there is no one "cutting edge of science," not even one cutting edge of genetics, and so we abandon one major area of investigation after another without giving a fair trial to the forgotten promises of past discoveries.

Sir Ronald A. Fisher is remembered as the father of modern statistics. Much of the backbone of quantitative genetics rests on his lifetime work. Sir Fisher surprised some genetics graduate students in a Raleigh, North Caroline "pub" on his last visit to the U.S. shortly before his death in the 1960s. These students had assembled, without faculty, at his request, where they expected to be tantalized by what Fisher saw quantitative genetics had to offer. The surprise came when Fisher asked, probably rhetorically, "what had become of all the wonderful work done in the area of cytogenetics over the last 30 years?" He obviously thought there was more potential to be mined than had been realized and was annoyed that the field had been so abandoned. Fisher's insight into a problem of science deals directly with our concern here.

In the progress of genetics, are those forgotten fields which can be further explored. We may have to set our sights lower than some of the pioneers in those fields had set for themselves and settle for longer time frames, more people involved and more money. But if we are thinking about a truly sustainable agriculture there will have to be many changes from top to bottom. There are many obstacles but that doesn't mean that it isn't worth a try and the pay off should yield untold dividends.

ANTICIPATED BENEFITS

Nine Considerations

The proposal for such a dramatic agricultural change understandably invites examination of how realistic are our hopes and claims. Though our vision is based on what we believe to be realistic knowledge and numbers, it is admittedly utopian; or perhaps more precisely, ecotopian, for it is more than a narrow and short-sighted human environment of concern here. We envision nine benefits to accompany such an agriculture. The first five involve resources and the last four are social considerations.

Resource considerations.

(1) We expect perennial agriculture to gradually accumulate soil soon after the net loss has been cut to zero. The fossil energy saving for fertilizer to replace this lost soil is significant.

(2) The efficiency of water utilization and water conservation by the perennial ecosystem would be near maximum and springs, long since dry or short-lived during the year, would return. Total irrigation would decline and this would reduce fossil energy use, both indirectly and on farm.

(3) The indirect consumption of fossil energy in agriculture's behalf would substantially decline. For example, the application of commercial fertilizer would be greatly reduced due to the use of legumes in the polyculture and through soil retention there would be savings in the N, P, & K in the soils which remain.

(4) Human-made pest control chemicals, especially those with no close chemical relatives in nature would be absent or nearly so. Besides the reduction in chemical contamination, a minor fossil energy saving would result.

(5) The direct consumption of fossil energy at the field level would be greatly reduced.

Social Considerations

(6) Long before such an agriculture is completely in place, because of efficiency in water usage, major policy questions surrounding the irrigation projects which promote aquifer mining or water diversions which lead to soil salting and silting problems become more manageable.

(7) Policy considerations which include equitable land ownership rather than major corporate control of land become more manageable due to reduced need for high capitalization on machinery, energy, farm chemicals, irrigation and seed.

(8) Over 100 million acres, currently set aside as marginal land, largely because of serious erosion potential under current cropping systems could be brought into production reducing the pressure for ever-increasing land prices. This increases the opportunity for more people to have a farm as a hearth, reducing the trend of the hearth giving way to the food factory.

(9) The time spent in the fields, over the course of a year would about equal the time spent in the food procurement process of "primitive" tribes today - 20 hours or less per person.

Soil and Energy

The primary purpose for developing such an agriculture is to save our soils from being eroded away or being chemically contaminated. We have calculated the anticipated yearly soil savings due to the presence of herbaceous perennials on 316 million U.S. acres currently planted to forage and annual grain crops (Table 8). The soil savings (numbers inside rectangle) is cal-

TABLE 8. Anticipated yearly soil savings (10^9 tons) due to presence of herbaceous perennials on 316×10^6 U.S. acres currently planted to forage and annual grain crops.

N-Year Replant Cycle	Millions of acres remaining unplowed annually	@ 5 tons/ acre[2]	@ 9 tons/ acre[36]	@ 12 tons/ acre[37]	@ 15 tons/ acre[3]	%Savings
		U.S. Soil Saving in Billion Tons				
1	0	0	0	0	0	0
3	211	1.06	1.89	2.53	3.16	67
5	253	1.27	2.27	3.03	3.79	80
7	272	1.36	2.43	3.25	4.06	86
10	284	1.42	2.55	3.40	4.26	90
20	300	1.50	2.70	3.60	4.50	95
Never	316	1.58	2.84	3.79	4.74	100

culated for any of the four national soil loss estimates by multiplying erosion rate by the annual unplowed acreage. For example, on a 3-year replant cycle, if we assume the Iowa State University estimate of an average of 12 tons/acre, the retained U.S. soil that would have otherwise moved seaward is 2.53 billion tons.

These numbers are conservative for they are not adjusted to account for the soil build-up during the unplowed years, nor are they adjusted to reflect that our plowed perennial fields, if they behave like plowed perennial pastures, will lose less soil the first year than a field which has experienced continuous cropping.[35]

The energy required to replace the nitrogen, phosphorus and potassium that is just in the eroded soil alone for this 316 million acres is shown in Table 9 for all four estimates of average tons per acre lost. It is easy to calculate once we know that to replace the N, P, and K lost in a ton of soil requires about 6% of a barrel of oil at the wellhead.

TABLE 9. Energy to Replace NPK over 316 x 10^6 Acres at Various Soil Erosion Rates

SOIL EROSION RATE (tons/acre)	5	9	12	15
TOTAL SOIL LOSS (10^9 tons)	1.58	2.84	3.79	4.74
ENERGY (10^6 bbl)	96.4	173.0	231.0	289.0

One ton of soil contains 3 lbs N, 2.4 lbs P, and 44 lbs K, which require respectively, 82,800; 13,990; and 176,000 BTU's to mine and process, for a total of 272,790 BTU = 0.061 bbl petroleum at the wellhead.[38]

When we compare the energy value of the N, P, and K lost through harvest of 100 bushels of grain from an acre versus 9 tons of soil lost on one acre, the energy value is nearly identical; more than half a barrel of petroleum at the wellhead for each case. These results are shown in the following calculation:

$$\begin{aligned}\text{Harvest} &= (30\text{ lb N})(27{,}600\text{ BTU/lb})+(15\text{ lb P})(5830\text{ BTU/lb})+(17\text{ lb K})(4000\text{ BTU/lb})\\ &= 2.21 \times 10^{6}\text{ BTU} + 0.087 \times 10^{6}\text{ BTU} + 0.068 \times 10^{6}\text{ BTU}\\ &= 2.37 \times 10^{6}\text{ BTU} = 0.53\text{ bbl petroleum at wellhead}\\ \text{Soil Loss} &= (9)(3\text{ lb N})(27600)+(9)(2.4)(5830)+(9)(44)(4000)\\ &= 0.745 \times 10^{6} + 0.126 \times 10^{6} + 1.58 \times 10^{6} = 2.45 \times 10^{6}\text{ BTU}\\ &= 0.55\text{ bbl}\end{aligned}$$

We have estimated the energy value of the N,P, and K which we anticipate would be saved each year over the 316 million years given several replant cycles. Once again, we have calculated this by assuming the 5, 9, 12 and 15 ton soil loss per acre estimates (Table 10).

TABLE 10. Energy Value (10^6 bbl petroleum, wellhead) of N, P, & K in Anticipated Soil Saved Annually (Table 1) on the 316 x 10^6 Acres.

N-Year Replant Cycle	Millions of acres remaining unplowed annually	@ 5 tons/ acre[2]	@ 9 tons/ acre[36]	@ 12 tons/ acre[37]	@ 15 tons/ acre[3]	% Savings
		Millions bbl of Energy Saved				
3	211	66.8	119	159	199	67
5	253	80.0	143	101	239	80
7	271	85.7	153	205	256	86
10	284	89.5	161	214	268	90
20	300	94.5	170	227	284	95
Never	316	99.5	179	239	299	100

Anticipated Energy Savings Due to Reduced Traction

Though the primary purpose of such an agriculture is to preserve and pass on a healthy soil, the most obvious and directly observable benefit will be a reduction in fossil energy input beginning at the field level. The top 10 grain and forage crops currently grown on the 316 million acres considered here now require, at the field level, 71.48 million barrels of petroleum at the wellhead (Table 11). This amounts to about a 4-day supply at the 1980 level of petroleum consumption. With a reduction in preplanting, planting, cultivation and fertilizer and pesticide application and with the annual harvest costs remaining fixed, we can expect a substantial savings in traction energy, perhaps as much as half or more.

TABLE 11. Annual Traction Energy in 10^6 bbl Petroleum at Wellhead[39]

CROP	PREPLANT, PLANT & CULTIVATE	FERTILIZER & PESTICIDE APPLICATION	HARVEST	TOTAL	10^6 ACRES
CORN	10.40	1.24	5.30	16.94	65.194
WHEAT	8.04	0.45	2.32	10.80	71.169
SOYBEANS	9.58	1.13	2.14	12.85	53.582
ALFALFA	0.85	0.23	7.75	8.82	26.642
CORN SILAGE	1.58	0.15	3.07	4.81	10.695
COTTON	4.65	0.74	1.75	7.15	13.731
GRAIN SORGHUM	2.93	0.14	0.67	3.74	13.917
OATS	1.43	0.09	0.62	2.14	18.136
BARLEY	1.02	0.06	0.29	1.38	9.153
HAY	0.34	0.09	2.42	2.85	33.904
	40.82 +	4.32 +	26.33 +	71.48	316.123

It is likely, at least in the early stages of perennial polyculture development, that every few years, the mix will have to be plowed and re-seeded. The annual traction energy saved, therefore, depends on the percent of the 316 million acres which do not experience the erosion promoting exercises of preplanting, planting, and cultivation, or the application of unhealthful petrochemicals. As mentioned, there would be no harvest saving and there would be a minimal increase in energy cost for seed separation of the polyculture when it is considered desirable to separate the mix. Since the preplanting, planting, cultivating and petrochemical application on the 316 million acres amounts to 40.82 + 4.32 or 45 million barrels of petroleum at the wellhead (Table 11), the annual energy savings is found by multiplying the percent of the 316 million acres that are not plowed times 45.14 million barrels. Table 12 displays estimates for six different replant cycles.

TABLE 12. Anticipated Annual Traction Energy Savings

N-Year Replant Cycle	10^6 Acres Remaining Unplowed Annually	% of 316×10^6 Acres Unplowed	Annual Traction Savings (10^6 bbl)	% of Present Fuel Use in Traction on 316×10^6 Acres
3	212	67	30.2	42
5	253	80	36.1	51
7	272	86	38.8	54
10	284	90	40.6	57
20	300	95	42.9	60
never	316	100	45.1	63
Presently Consumed	316	100	71.48	100

Anticipated Annual Equipment Manufacture Savings

Energy at the field level is not all we save. With a reduction in machinery use, the savings in equipment manufacture is proportional to the reduction in equipment use overall. We have estimated the energy savings for reduced equipment manufacture and repair (Table 13) again expressed in barrels saved at the wellhead.

TABLE 13. Anticipated annual equipment manufacture savings due to reduced preplanting, planting and cultivation over 316 x 10^6 U.S. acres currently planted to forage and annual grain crops

N-year Replant Cycle	10^6 barrels petroleum saved at wellhead	% of present use
3	16.1	42.1
5	19.3	50.5
7	20.7	54.2
10	21.7	56.8
20	22.9	59.9
Never	24.1	63.1
Present equipment manufacture energy	38.2	100.0

These numbers were derived indirectly. Steinhart (1974)[40] calculated the energy cost to manufacture equipment for all U.S. agricultural acreage, rangeland included. This does not accurately reflect the high average equipment energy cost per tilled acre which we obtained by considering the fuel use in comparison to equipment manufacture and repair. There are several sources with the results summarized below.

Conventional Agriculture Corn Production Estimates	Millions of Btu's/acre		Traction Equipment Ratio
	Traction	Equipment	
Pimentel & Terhune (1977)[41]	3.46	1.85	1.87
Pimentel et. al. (1973)[42]	3.2	1.7	1.86
Vaughn (1978) (Virginia only)[43]	1.2	0.7	1.71
Roller (1975)[44]	1.2	0.7	1.71
USDA data base (1974)[39]	1.16	---	----

From the above traction/equipment ratios we have chosen 1.87 since it is the most recent. Thus for the 316 x 10^6 acres, we calculate that the present equipment manufacture energy = present traction ÷ 1.87 = 71.48 x 10^6 bbl ÷ 1.87 = 38.2 x 10^6 bbl. Likewise, the other numbers in Table 11 were derived from Table 10.

Pesticide Savings

Pesticides. U.S. farmland received 641 million pounds of active pesticide ingredients in 1974. Half were herbicides, nearly 30% insecticides and 15% fungicides.[45] Nearly as much, about 500 million pounds were used in 1970 by government, industry, homeowners and for mosquito control.[46] Cotton, corn and soybeans are the big users in the U.S. and in 1974 accounted for 37%, 30% and 15% respectively for the energy used to manufacture these pesticides and provide the carrier solution. Corn acreage received 33% of all herbicides and cotton ground received 42% of all insecticides by weight in 1974.[45] In 1976, it was estimated that 90% of the corn crop and 80% of the soybean acreage received pesticides. In 1971, 47% of the wheat acreage was treated and overall 52% of all cropland received pesticide chemicals.[47]

All the pesticides applied to the top 10 crops growing over the 316 million acres had an energy value equivalent to only 11.47 million barrels at the wellhead (Table 14). Though the energy savings would be insignificant if we were to completely eliminate all pesticides from this acreage (.05% of 1980 oil consumption), perennial polyculture could eliminate at least two-thirds the total now used. The problem is cotton which consumes over a third of the total energy value of these pesticides now.

The major benefit from decreased pesticide use is not the energy saved in manufacture of the products nor in field application. It simply reduces widespread contamination of the countryside. Species diversity, as through polyculture, breeds dependable chemistry and has a multiplier effect on the kinds of seldom-seen teeming diversity below.

If our new perennial crops, particularly the legumes, are allowed to retain the chemicals from their wild ancestors which make them unpalatable to humans and livestock as well as to the insects and pathogens who would harvest them before we do, we could reduce the chemical impact on the environment many fold. If plants grow the chemical resistance, (a solar pesticide program), then the chemical is where it is needed and it has been provided through the use of sunshine. When we spray, often less than 1 percent strikes the target. But how are humans to eat such seeds? The same industries that brought us processed foods can be the same industries that process the inpalatable grains to remove the protection after harvest.

TABLE 14. Energy Cost to Manufacture the Present Annual Consumption of Fertilizers and Pesticides on the 316 x 10^6 Acres.[45]

	10^6 bbl. petroleum, wellhead	
CROP	FERTILIZER	PESTICIDE
CORN	54.05	3.40
WHEAT	19.72	0.17
SOYBEANS	3.59	1.67
ALFALFA	1.62	0.57
CORN SILAGE	7.82	0.55
COTTON	7.76	4.22
GRAIN SORGHUM	7.43	0.83
OATS	2.84	0.03
BARLEY	2.52	0.03
HAY	11.33	0.002
TOTAL	118.68	11.47

Anticipated Fossil Water and Energy Related Savings

The energy required to pump all water to irrigate 1974 crops[45] amounted to 59.4 million barrels of oil equivalent at the wellhead. The energy required to apply this water on the 316 million acres of cropland discussed here, amounts to 42.2 million barrels - 72% of all.

Groundwater for irrigation[48,49] is 68% by volume of all groundwater used in the U.S. Our best guess is that groundwater mining for irrigation is likewise 68% of all groundwater mined each year (23.3 million acre-feet in 1975)[50] or 15.8 million acre-feet. Fifty-two million wellhead barrels equivalent were used on farms to pump 51.5 million acre-feet of irrigation groundwater,[51] then proportionally, 15.8 million acre-feet required 16.0 million barrels at the wellhead.

If we assume the 316 million acres accounted for 72 percent of all U.S. on-farm irrigation (groundwater and surface) energy at the pump,[52] proportionally then, 72 percent of 16.0 million barrels or 11.5 million wellhead barrel-equivalents were used for mining groundwater to irrigate. Therefore, if we were to stop mining water for agriculture (not for domestic use), we would save the equivalent of nearly 2/3rds of a day's current oil consumption.

We know it is unrealistic and unnecessary to stop all irrigating in the United States, but if perennial polyculture, because of increased efficiency of water use, could reduce the need to mine fossil water for irrigation, not only would it prevent an annual overdraft of 15.8 million acre-feet, the energy savings would be equivalent to 11.5 million wellhead barrels. Mining energy to mine water to grow food for a cattle and pig welfare program which will in turn convert high quality grain at less than 10% efficiency is questionable resource management.

TABLE 15. Energy Used for On-Farm Crop Irrigation on 316 x 10^6 Acres in 1974.

CROP	Irrigation Energy (10^6 bbl)
ALFALFA	6.67
CORN	10.24
COTTON	6.99
GRAIN SORGHUM	8.14
WHEAT (Winter & Spring)	4.77
HAY	2.39
CORN SILAGE	1.58
BARLEY	0.89
SOYBEANS	0.39
OATS	0.15
	42.21

Contribution To Nutritional Balance

We have estimated the energy savings for traction and reduced equipment manufacture we might expect once perennial roots are firmly in place. Soil erosion is slowed to natural replacement levels. We are still faced with the problem of nutrient mining from harvest and the high energy cost of recapturing nitrogen from the atmosphere each year.

We might expect perennial polycultures to possess, like their analogs in nature, an efficient nutrient conservation program. Even so, there will still be an energy cost to return a proportional supply of nutrients, including atmospheric nitrogen to the system each year. The question is, how much will be done by solar and how much by fossil fuel?

To obtain an estimate of the effectiveness of HPSPP over the 316 million acres we need to know how many nutrients are being removed due to grain harvest now and their energy value. Table 16 shows that harvest of the top 3 crops (corn, wheat & soybeans) in 1979, resulted in a nutrient removal of 15.58 billion pounds of nitrogen, 2.23 billion pounds of phosphorus and 4.24 billion pounds of potassium. These crops were grown over a total of 200 million acres (Table 16).

The alfalfa/hay mix grown on 60 million acres contained 5.94 billion pounds of nitrogen, 0.62 billion pounds of phosphorus and 4.97 billion pounds of potassium (Table 16).

We can say, therefore, that 260 million of the 316 million acres experienced a total nutrient removal of 21.52 billion pounds of nitrogen, 2.85 billion pounds of phosphorus and 9.21 billion pounds of potassium. These are huge numbers which begin to take on a greater significance when we consider the energy cost for replacing them, or looked at in a slightly different manner - their energy value.

Let us assume that grains of the future will experience an annual yield of 1800 lbs. of mixed grain per acre. Though the overall yield is less than what these acres experience now, we assume the same nutritional mix as corn, wheat and soybeans taken collectively, weighted according to the mix within each crop and the total pounds each crop contributes to the grain supply. As seen in Table 16, each pound of thoroughly mixed grain would consist of 2.4% nitrogen, 0.35% phosphorus, and 0.66% potassium. Consequently, if our perennial grain mix is to have the same nutritional mix; at 1800 lbs./acre and 0.024 pounds of nitrogen/pound of grain, an average acre would require 43.2 pounds of nitroge. Similar multiplying gives us an acre requirement of 6.3 pounds of phosphorus and 11.9 pounds of potassium.

For the 60 million acres devoted to alfalfa and hay the mix changes, particularly with respect to potassium. As shown in Table 16 again, the nitrogen requirement is about the same: 0.022 vs. 0.024/lb. Hay requires considerable less phosphorus but 2.7 times as much potassium per pound than grain.

Mixed perennials could, theoretically, be sources of both grains and hay. But if a grain harvest has already been realized, we assume the hay harvest should not require more than one-half ton per acre. For comparison, the average alfalfa field will yield 2.7 tons and an ordinary hay field about 2 tons/acre/year. We would have to harvest only 873 pounds from each of the 316 million acres to meet the current alfalfa/hay demand.

If we were to only harvest 873 lbs. of hay/acre, with appropriate weighting, we calculate that 22 lbs of nitrogen, 2.2 lbs phosphorus and 18 lbs of potassium/acre would be necessary (Table 16).

To estimate the total nutrient removal from a 1800 lb./acre mixed grain harvest plus the removal of 873 pounds of hay from the same acre, we can simply add the nutrient harvest from the grain and hay per acre to learn the total nutrient demand/acre as shown below:

	N	P	K
Grain	43.2	6.3	11.9
Hay	19.1	1.9	15.7
	62.3 lbs	8.2 lbs	27.6 lbs

Table 16. Determination of NPK mix for HPSPP Grain and Hay

Crop	10^6 Acres (1979)	lbs/ Acre	Total 10^9 lbs	lbs N/ lb Crop*	Total N 10^9 lbs	lb P/ lb Crop*	Total P 10^9 lbs	lb K lb Crop*	Total K 10^9 lbs
CORN	70	6000 (100 bu)	420	.015	6.30	.0026	1.09	.0037	1.55
WHEAT	60	1800 (30 bu)	108	.020	2.16	.004	0.43	.0050	0.54
SOYBEANS	70	1620 (27 bu)	113	.063	7.12	.0063	0.71	.019	2.15
		TOTAL	641		15.58		2.23		4.24
ALFALFA	26	5400 (2.7 tons)	140	.023	3.22	.0023	0.32	.019	2.66
HAY	34	4000 (2.0 tons)	136	.02	2.72	.0022	0.30	.017	2.31
		TOTAL	276		5.94		0.62		4.97

NPK Mix per lb				
	Grain:	0.024 lb N	0.0035 lb P	0.0066 lb K
	Alfalfa & Hay:	0.022 lb N	0.0022 lb P	0.018 lb K

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*See Reference 53.

Let us assume that the entire 316 million acres (Not the 200 million acres) would be planted to mixed seed producing perennials yielding at 1800 lbs. per acre and 873 pounds of hay per acre. The total removal of NPK for grain and hay is shown both separately and together in Table 17.

TABLE 17. Removal of NPK (10^6 tons) from 316 x 10^6 HPSPP, Based on 1800 lbs. Grain/Acre, 873 lbs Hay/Acre.

	N	P	K
Grain	6.8	0.99	1.8
Hay	3.1	1.18	2.5
TOTAL	9.9	2.17	4.13

Let us pretend we are clever enough to return all the U.S. animal manure and all human manure to this landscape. The quantities of NPK which would be returned in such a case are shown in Table 18.

TABLE 18. Available NPK from All U.S. Animal and Human Manure (10^6 tons)

	N	P	K
All U.S. Animal Manure[a]	2.6	1.00	2.30
All Human Manure[b]	0.34	0.17	0.13
TOTAL MANURE	2.94	1.17	2.43

[a] Includes losses from manure voided directly on grassland and from storage and waste-handling systems. See Reference 54.

[b] NPK Available From Human Manure in the U.S., includes losses.

Composition of Human Excrement[55]

	Dry Feces (lbs/year)	Urine Solids (lbs/year)	Composition of Both Urine & Feces, Dry Basis % N	% P	% K
Range of Values	29-58	44-58	5-7	1.3-2.4	0.8-2.1
Authors' Choice	40	50	6	2	1.5

The total annual dry manure per person = 40 lbs + 50 lbs = 90 lbs. For a U.S. population of 230×10^6 people, the total nutrient available is:

$N = (230 \times 10^6)(90 \text{ lbs})(6\%) = 0.62 \times 10^6$ tons, but at 33% loss due to volatilization $= 0.42 \times 10^6$ tons.

$P = (230 \times 10^6)(90 \text{ lbs})(2\%) = \underline{0.21} \times 10^6$ tons.

$K = (230 \times 10^6)(90 \text{ lbs})(1.5\%) = 0.16 \times 10^6$ tons.

Clearly we have a nutrient deficiency, some of which can be accounted for by the nitrogen loss due to volatilization. Much of the rest must be due to export to other countries. Because nitrogen is part of the atmosphere, its loss to the plant community is energy loss. Phosphorus and potassium loss is a loss from the square foot where it was taken up by the growing plant. For the phosphorus and potassium, the difference between that which was removed by harvest and what could be returned through the manure of humans and animals must reside in the corpses of people who died during the year, the growth of the young and the export (probably the largest component) to foreign lands. The 7 pound/acre nitrogen deficit is significant only because of the high energy which must be spent to get it back. Nitrogen bonds are among the strongest in nature and are not broken without a substantial cost somewhere in the food production system. The very small phosphorus deficit, about 1.0 pounds per acre and the 1.7 pound potassium deficit would have to be returned from outside the "ground to mouth" system since they do not float around in the air. Incidently, a major difference in the soils of organic vs. conventional farms in the study directed by William Lockeretz was the deficiency of P and K on the organic farms.[56]

The energy cost to replace these three nutrients now shipped from these 316 million acres to accomodate all 10 crops is about 118.68 million barrels at the wellhead (Table 14). A glance at Table 14 will show that corn and wheat are the top two fertilizer consumers. Hay is third. Soybeans and alfalfa, both legumes, require less applied fertilizer. But the heavy demands of corn, wheat and hay drastically offset the smaller demands of soybeans and alfalfa. Therefore, when we imagine that our fields would provide a nutritional profile similar to our corn and soybeans as well as a nutritional profile of hay and alfalfa, even with a harvest of only 1800 pounds of grain per acre plus 873 pounds of hay, the nutrient demand would be in excess of what these fields are producing now, 133.09 million (Table 19) vs. 118.68 million wellhead barrels.

TABLE 19. Energy (10^6 bbl petroleum at the wellhead) to Manufacture the NPK which would be removed from Harvest of Polycultures over 316 x 10^6 Acres

	N	P	K	TOTAL	
Grain	84.4	2.60	3.36	90.36	
Hay	37.5	0.79	4.44	42.73	
Total	121.9	3.39	7.80	133.09	119 x 10^6 bbl now applied

[*] To Mine and Process: N - 27,600 BTU/lb; P - 5,830 BTU/lb; and K - 4,000 BTU/lb.[57]

What if we were to use sunlight to make some of these nutrients available? The energy value for phosphorus and potassium isn't much, only about 11.2 million wellhead barrels (Table 20). In other words, what if we were to get by with less nitrogen provided by the fossil-powered industrial process and rely more on legumes and the other sources from nature? As one might expect, the energy cost drops in proportion to the amount of nitrogen produced (Table 20).

TABLE 20. Energy (10^6 bbl petroleum at the wellhead) to Manufacture All the P & K and Various %'s of N Removed by Harvest of HPSPP Grain and Hay

	10% N	25% N	50% N	75% N	90% N	100% N
N	12.2	30.5	61.0	91.4	109.7	121.9
P & K	11.2	11.2	11.2	11.2	11.2	11.2
TOTAL	23.4	41.7	72.2	102.6	120.9	133.1

Since nitrogen, unlike P and K, is all around in the air, we can examine the feasibility of reducing the consumption of industry-produced fertilizer by substituting legumes and thereby use solar instead of fossil energy.

Remember we expect to remove 43.2 pounds of nitrogen with harvest. Let us consider a mid-summer harvest of prairie hay in which the remaining stubble and growth for the remainder of the year represent the straw left behind. Thus all the nitrogen removed in prairie hay is regarded as the nitrogen that would be removed from the grain produced in the HPSPP. If 2000 pounds of prairie hay per acre is harvested annually with a protein content of 7.8% and with the nitrogen content of protein being 16%, then 25.0 pounds of nitrogen is harvested per acre.[58]

This is much less than the 43.2 lbs nitrogen harvested in the 1800 lbs. of grain, so legumes will have to be added to the composition of the HPSPP to replace the additional 18.2 lbs nitrogen (43.2-25=18.2) removed annually. Based on J.E. Weaver's studies which show that forbs comprise only 2.2% of the tall-grass prairie by basal cover,[59] the percentage composition of legumes is probably on the order of 1% of the prairie. Thus the prairie receives more nitrogen from the atmosphere, rain, and asymbiotic N fixation than from its legume population.[60] Apparently the prairie operates on much less N than our agricultural experiences would lead us to expect. Recovery of mineralized nitrogen by the prairie must be highly efficient as well, a condition one could guess is enhanced by the suppression of nitrification due to the release of inhibitors from the rhizomes of the climax grass species.[61] This is of considerable advantage for HPSPP, which we consider the ecological analog of the prairie, because annuals, which is what our present grain crops are, do not have rhizomes. Perhaps we can expect a similar response in our domestic prairie of the future. If we can't count on such an advantage we can estimate the need as follows. An alfalfa crop plowed under may provide as much as 80 pounds of carry-over nitrogen for a successive crop.[62] If we take this as our standard, the additional 18.2 lbs of N needed for grain production might be supplied by a HPSPP in which 23% of its composition is legumes.

So far, we have only considered the grain yield. Remember, if we take the 276 billion ton hay harvest from 60 million acres and spread it over 316 million acres, our herbaceous perennials will have to yield 873 pounds an acre. At 0.022 pounds of nitrogen per pound, we would need 19.2 additional pounds of nitrogen to support the hay crop. Based on the assumptions in the above paragraph pertaining to the ability of legumes to supply the nitrogen, we would need about 24% additional legumes pushing the total legume mix close to 50%.

This seems like a far too rich legume mix and there may be a way out, but it is not encouraging. To export the hay may not be the best thing to do. If the 873 lbs. of hay/acre is grazed off by cattle rather than exported as bales, then only 62.5%, 20% and 10% of the N, P, and K respectively in the hay would have to be replaced by commercial fertilizers, with the rest being recovered through the solid and liquid manures of the cattle. Applying these percentages to the hay values in Table 16, we derive the following table:

TABLE 21. Energy (10^6 bbl petroleum at the wellhead) to replace the NPK removed by harvest of 1800 lbs/acre grain and grazing of 873 lbs of hay/acre on 316 million acres.

	N	P	K	Total
Grain	84.4	2.60	3.36	90.36
Hay	23.5	0.16	0.45	24.11
	107.9	2.76	3.81	114.47

This acreage would support 36 million cattle of which we could harvest 12 million per year. Thus about 10% of the nitrogen is returned and about half the P and K. There is an advantage to returning manure, but in the longer run we have to hope for an improvement in the recovery of mineralized nitrogen due to the enzymatic release and reduced nitrogen loss overall.

Sylvan Wittwer, Assistant Dean of Agriculture at Michigan State has discussed recent studies which indicate "that 25 percent of fertilizer nitrogen is lost to denitrification under normal agricultural conditions. Losses from nitrification are equally as great. Assessments of the fate of soil applied nitrogen fertilizer suggest that 25 to 35 percent is lost both by nitrification and denitrification."[63] Wittwer continues that there are "many variables that affect these losses. Some can be controlled. Root zone placement of fertilizer helps reduce the losses." Wittwer continues that nitrification inhibitors, both natural and synthetic, applied with ammonia or urea, are effective deterrents to leaching and atmospheric losses of nitrogen. Denitrification inhibitors will also soon be available." These are optimistic words which encourage us to feel there is as much justification to expect a suppression of nitrification due to the release of inhibitors from the rhizomes of the perennial grass species as there is to expect the "eventualities" outlined by Dr. Wittwer. Perhaps a 23% legume mix in a perennial polyculture is more than enough.

Energy Cost Estimate For Separation of Seeds Harvested from HPSPP

A final energy consideration is in order. What would be the energy cost for seed separation from a polyculture harvest?

The Burrows Seed and Grain Cleaner,[58] which is operated with a 3/4 hp motor (=.56 kw), can clean 100 bushels of wheat in one hour at an energy expenditure = (3/4 hp) x (1 hour) = .56 kwhr = 1,900 Btu. With a motor that is 85% efficient and a 30% electrical conversion efficiency from the coal to the outlet, the cleaning of 100 bushels of wheat requires 7,450 Btu of primary energy. If we assume that HPSPP have the same yield as wheat, or 30 bushels an acre, and that the energy for a cleaning operation is roughly equal to separation of seeds, then 2,240 Btu of primary energy are needed to separate the grain yield from one acre of HPSPP. This amount of energy is small compared to the annual energy/acre requirements for various traction operations for wheat:

TABLE 22. Energy Cost of Pre-Planting, Planting, Harvest Compared to the Estimated Cost of Separating Seed From a Polyculture Harvest.

	Btu/acre	bbl. petroleum, wellhead/acre[59]
preplant	405,000	0.091
plant	95,000	0.021
harvest	161,000	0.036
Total	661,000	0.148
Seed Separation	2,240	0.00050

If all the grain from the 316 million acres had to be separated, and making the very soft assumption that energy cost for separation would equal cleaning on a per pound basis, 150,000 barrels of petroleum equivalent would be necessary. This is such a small additional amount that even if we must double or quadruple the energy it is still a relatively small energy input. In fact, scarcely any of this grain would need separated since most would be fed to livestock. One would expect that supplementary grains would be added as needed to balance out the nutritional requirements of the livestock.

Summary of Anticipated Energy Savings

The energy used on the 316 million acres is around 284 million wellhead barrels equivalent (Table 23). As seen in the table, we have divided this energy into two categories; fixed and variable. The fixed energy inputs are energy bills that must be paid independent of the replant cycle. Obviously we wish to cut down the huge energy cost for providing fertilizer as this amounts to over 42% of all energy spent at the field level. There are numerous unknowns as to how much nitrogen a given acre with legumes in the mix can capture though we have tried to estimate it. We don't know how much the rhizomes in the grasses of that mix can suppress nitrification due to the release of inhibitors. Perhaps as important, we can not tell how much more efficiently these "domestic prairies" of the future can capture and hold the rain and snow and thereby better allocate nature's nitrogen which they contain. For this summary on energy savings in fertilizer use, we are allowing our optimism to match the optimism which comes through in Professor Wittwer's words quoted on pages 54 and 55. We will assume then, that all the nitrogen demands of a perennial polyculture can be met by the "ecosystem" thereby saving 110 million barrels of wellhead oil equivalent (Table 24).

TABLE 23. Energy Used on the 316 x 10^6 Acres in 1974.

FIXED	10^6 bbl. wellhead
Fertilizer (NPK)	122
Pesticides	11
Irrigation	42
VARIABLE	
Traction	71
Equipment	38
TOTAL	284

TABLE 24. Anticipated Annual Fixed Energy Savings on 316 x 10^6 Acres

	10^6 bbl. wellhead
Fertilizer	
(NPK)	+ 122
(P&K replacement after harvest)	- 12
Pesticides	+ 7
Irrigation mining	+ 12
	129

The table will show that the energy cost to replace the P and K would continue and therefore cannot be subtracted. Pesticide application could decrease largely due to the virtue of polyculture. A major concern is the problem of providing enough cotton fiber for the population. Cotton monoculture grown on bottom lands would be preferable to being grown on rolling or hill country. In the case of cotton, the pesticide impact is significant. Since cotton now consumes over a third of the total pesticides applied now, we subtract off 4 million bbl. oil equivalent leaving 7 million barrels saving on pesticide use.

The last fixed energy saving would be the reduction in irrigation mining. If we quit mining ground water to irrigate, we would save about 12 million wellhead barrels. This is a policy which should be followed whether we are growing annual monocultures or perennial polycultures.

Our fixed savings, overall, then amounts to around 129 million wellhead barrels. The variable savings is dependent upon the replant cycles discussed earlier in this section. One interesting result of our analysis is that the difference between a 3 year replant cycle and a 20 year replant cycle amounts to only 20 million barrels per year, the difference between 175 and 195 million barrels (Table 25).

We have not included the energy cost for seed separation for, according to our estimates, it would be miniscule.

TABLE 25. Annual Variable and Fixed Energy Savings (10^6 bbl. wellhead)

	N-Year Replant Cycle					
	3	5	7	10	20	Never
Variable						
Traction	30	36	39	41	43	45
Equipment	16	19	21	22	23	24
Fixed	129	129	129	129	129	129
Total	175	183	189	192	195	198
% of Never	88	92	95	97	99	100
% of Energy Used in 1974	63	65	68	69	70	71

Concluding Remarks. Tables 10 and 25 are important, though partial, summaries for this report. Table 10 considers the energy value of soil that would be saved for future years, including future generations. In the future, though the energy value may not change, the monetary cost seems certain to increase steeply. Table 12 is an estimate of the energy savings we would experience in any one year. A combination of these tables reveals that we can continue to have an energy value loss of 242 - 497 million barrels of oil equivalent per year. The combined annual savings, including the energy value of soil saved as well as direct dollar savings amounts to $8.5-$17.4 billion, in 1980 dollars. The 1980 foreign exports of agricultural products is estimated at $40 billion.

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Appendix I

Taxonomy of Polyculture (Crop mixtures or crop associations)

Annual Polyculture

- Multiple cropping - Growing more than one crop on the same land in one year
- Maximum cropping -- Attainment of the highest possible production per unit area per unit time without regard to cost or net return
- Mixed cropping - Two or more crops grown simultaneously and intermingles with no row arrangement.
- Intercropping - Two or more crops grown simultaneously in alternate rows in the same area, or more generally "growing two or more crops simultaneously on the same field in a year."
- Relay planting - The maturing annual crop interplanted with seedlings or seeds of the following crop (ref) (Harwood) If the flowering period of one crop overlaps that of the second crop in the field then this is inter-cropping, or in the phrase of Andrews & Kassam, relay inter-cropping.
- Interplanting - Long-term annual or biennial crops interplanted with short-term annual crops during early stages of plant development
- Interculture - Arable crops grown under perennial crops.

Perennial Polyculture

- Mixed Ligneous - Mixed trees or shrubs or a mixture of trees and shrubs maintained or preserved for purposes of human consumption (Includes woodlots, managed or otherwise or orchards, natural or cultivated forests)
- Herbaceous
  - vegetative - forage purposes; includes native pastures, domestic pasture land or mixed stands planted to produce hay for harvest.
  - fruit/seed - The type of sustainable agriculture discussed here.

Appendix II

Comparison of two minimum soil loss agricultural practices

	Minimum or No-Till	Perennial Polyculture
Features	annuals	perennials
Roots in ecosystem	dead, much of year	alive, year-round
System	monoculture	polyculture
Herbicide	yes	no
Cropping	rows	with or without rows; probably with
Planting	annually	once every 3-10 years; perhaps less often.
Soil Loss	negligible	negligible
Soil Moisture Conservation	yes	yes
Soil Organic Matter High	yes	yes
Crop Rotation	yes	greatly reduced if at all
Mulch present	yes	yes
Soil compaction	yes	no
Soil preference	sandy & medium textured	no
Weed problems	perennial weeds & decreased herbicide effectiveness	no or limited

Work Statement

Polyculture of Herbaceous Perennial Plants as a Technology for Enhancing the Sustained Productivity of U.S. Croplands

1. Describe the technology of herbaceous perennial polyculture.

   . This has been discussed in the body of the text, particularly in II. THE BIO-TECHNOLOGY.

   How would its short-term productivity compare to that of conventional agriculture?

   . If one is looking at the bottom line of yield alone at present, it can not compete. If however, we were to allocate no more fossil fuel to conventional agriculture than the agriculture proposed here, conventional agriculture would likely not compete with what we have envisioned here.

   How would it compare in terms of sustainability?

   . Conventional agriculture is more soil wasting and fossil fuel dependent and therefore compares unfavorably with the agriculture proposed here.

   In terms of profitability?

   . Again, in a society with a fossil fuel glut, where the true price is not paid for oil, herbaceous perennial polycultures can not compete. As oil costs increase, however, herbaceous perennial polycultures would become increasingly favorable.

   In terms of susceptability to shortfalls caused by environmental variables or by other factors?

   . The chemical diversity of a polyculture, if it is like natural ecosystems, makes it less vulnerable to insects and pathogens. The more efficient retention and use of soil moisture by perennial roots vs. a plowed field makes the ecosystem more resilient.

   . Reduced soil loss means retained fertility even after severe rainstorms.

2. What plant taxa are most likely to be involved (specify species if possible)?

   . The three principle families likely to be involved, in the order of their relative numbers (not importance) are the grasses, legumes and composites, particularly the sunflower tribe. The species are listed in the text, particularly in the tables 1-7, in the section entitled "Yields of some select perennials."

2. What plant taxa . . . (continued)

What parameters would determine whether a particular taxon would be suitable for the technology?

- Moderate to strong perennial (i.e. not annual that is sometimes perennial or biennial) that will not winter kill (unlike sorghum).
- Must show promise as a potentially high seed yielder unless it serves another role such as being a strong nitrogen fixer or natural repellent of insects and pathogens for associated species.
- Should suggest some potential for determinate seed set.
- Should promise a relatively high yield for a minimum of 3 years in order to accomodate itself to a 3 year or more replant cycle.
- If the species is of polyploid or hybrid origin, the probability of regular meiosis should be very high or show some promise of high regularity.
- Should only be weakly allelopathic if at all.

How much is known about these parameters for the plant taxa now considered likely candidates for the technology?

- The species listed below (an alphabetical compilation by family of all species listed in Tables 1-7) are perennials selected on the basis of their promise for high seed yield.
- We don't know their potential for determinate seed-set, but at this time consider every herbaceous flowering plant to possess this potential.
- We don't know what the average yield might be for 3 years and more, except where indicated in the tables. More experimental work needs done in this area.
- Literature is available on the cytology of most of these species, especially with respect to chromosome counts, ploidy levels, etc., but we doubt that meiosis has been studied in most of them. We intend to do an extensive literature review in both these areas.
- We have not done a literature search on the allelopathic situation for any of these species.

Thirty-nine Taxa Mentioned In This Paper

Composites

Engelmannia pinnatifida
Helianthus maximilliani
Liatris asper
Liatris pycnostachya
Ratibida pinnata

Legumes

Astragalus cicer
Desmanthus illinoensis
Lotus corniculatus
Medicago sativa
Onobrychis viciaefolia
Trifolius hybridum
Trifolium pratense
Vicia villosa

Grasses

Agropyron cristatum
Agropyron elongatum
Agropyron intermedium
Agropyron smithii
Agropyron spicatum
Agropyron trachycaulum
Agropyron trichophorum
Andropogon gerardi
Bouteloua curtipendula
Bouteloua gracilis
Bromus inermis
Bromus marginatus
Buchloe dactyloides
Dactylis glomerata
Elymus canadensis
Elymus junceus
Eragrostis curvula
Eragrostis trichoides
Festuca arundinacea
Lolium multiflorum
Lolium perenne
Orzopsis hymenoides
Panicum virgatum
Sorghastrum nutans
Sporobolus cryptandrus
Stipa viridula

3. Where do research and development priorities lie for this technology?

   - We envision 10 major research and development tasks for this technology. These tasks and the professions best suited for carrying them out are outlined on the last page which includes recommendations as to how $100 million might best be spent over the next 10 years for the development of this bio-technology.

4. Under what conditions is the technology most likely to be successful (or where is it most likely to be implemented first on a large scale)?

   - We would expect that most perennial polycultures would first be grown on marginal land in the U.S. There is an abundant supply of such land for it currently totals over 100 million acres. These polycultures could be safely planted on most of this acreage for they would substitute for much of the vegetative structure there now. Though yields would be lower on this poorer quality land, the penalty to the farmer would be much less in the initial stages than if these perennial mixes were planted on the currently cultivated landscape.

Under what environmental conditions, under what cost/price relationships as regards capital inputs and crop prices of various kinds, under what conditions of land tenure, labor cost and availability, etc., would this technology most likely succeed?

- The current land tenure conditions should be adequate to accomodate this proposed technology. The cost for seed bed preparation and planting should not exceed the cost for preplanting and planting mixed pastures now.

- There is little we can say about crop prices except that if mixed grains grown on marginal land become grain sources for livestock, this amounts to an economic plus for farmers accustomed to feeding the higher yielding grain crops.

- It is our guess that during the course of polyculture research and development that plant breeders at the land grant institutions will be assisted by their colleagues in agriculture engineering to make adaptations on conventional combines to harvest the experimental plots.

Where do these conditions exist or where are they likely to develop?

- The necessary conditions exist in America and this country seems to be the most likely place for the technology to develop.

5. Is the technology in use or even under investigation, elsewhere in the world than in the United States?

- Not that we are aware.

How is it similar to the polyculture techniques used in Asia, Africa, and Latin America? How is it different?

- Annual polyculture was formerly a widespread and extensive method in the so-called underdeveloped countries. The classic corn-bean mixes are probably the best known. Perennial polyculture in which fruit/seeds are harvested has been limited to woody vegetation.

- Herbaceous perennial polyculture in which seeds have matured at the same time would be substantially different than the polyculture of annuals or trees and shrubs. The latter do not lend themselves easily to machine harvest but the herbaceous perennial polyculture we envision does. Furthermore, these perennial seed producing mixes would not have to be grown in rows.

6. How does this technology compare to no-till agriculture; what are the similarities and differences.

- The two technologies have two similarities worth mentioning - no-till and reduced soil loss because of no-till. From there on, the differences between the two methods nearly over-shadow the similarities. No-till is pesticide dependent. Perennial polyculture is expected to be independent of pesticides. No-till features annuals in monoculture.

6. How does this technology compare . . . (continued)

Perennial polyculture describes the ecosystem and as such takes a step beyond mere method.

Does current research on no-till provide information useful for development of polyculture of herbaceous perennials?

- A limited amount, if any, that we can see at this time.

How would the need for inputs (e.g., fertilizers, pesticides, specialized germ plasm, net energy, labor, credit) compare to the inputs needed with conventional no-till?

- All inputs would be greatly reduced. In the text we speak to reduced fertilizer use, reduced pesticide application, less labor, less energy. Since we expect a reduction in all areas, there is, therefore, a reduction in capital investment and therefore reduced dependency on credit.
- Specialized germ plasm would be selected from the wild plants bred for high yield to mature in synchrony. Polyploid development and hybrids, many of them from wide crosses have been considered in the text.
- We did not compare no-till to the bio-technology proposed here. However, our specific information could be readily compared to information published elsewhere on the results of no-till farming.

7. What are the major constraints on the development of the technology?

- We see two contraints which impinge on the prospect for technology development.
  (1) Promoters of conventional agriculture believe the traditional soil conservation methods - terracing, grass water ways, check dams, contour farming, stubble mulching, conservation tillage, crop rotation, etc. - are adequate for the task. The apologists for conventional agriculture believe that where these methods are not practiced, farmer ignorance or farmer naughtyness is responsible. At the deepest level of contemplation, soil loss is regarded as a lack of exercise of stewardship. As outlined in the recent book by Wes Jackson (New Roots for Agriculture, Friends of the Earth, San Francisco), we believe the exercise of stewardship which employs the traditional measures may be beyond our ethical stretch.
  (2) A somewhat uncritical acceptance of the new herbicide-based no-till method for growing traditional row crops, particularly corn, is an indication that most agriculturists believe we have a technical fix already at hand to significantly reduce soil loss.

8. Describe a plausible scenario regarding development of the technology. Who would have to put what levels of development effort in for how long? What would be the role of government, academia, industry, farmers & consumers?

- The research and development effort (see number 3) which includes 10 major task areas (last page)describes who we think would have to be primarily responsible for development of this bio-technology.

It appears upon first consideration that we can expect little from the private seed companies. Who can blame them for not producing a perennial or groups of perennials that could put them out of business? If they are left out of the action, it seems to us, it would be unfortunate, for these companies have important resources, particularly manpower for extensive analysis, an absolute necessity if new crops are to be developed. If these companies are to be involved, what they will likely want in return are patents on their products.

There has been considerable concern among many New Age Environmentalists that plant patenting leads to an unacceptable level of centralized control over food production. On the other hand, if a seed company could be granted a patent on a particular crop or crop mix that was perennial, then there would be a strong incentive to increase the variety of useful plants. This could be managed in many ways, but one possibility would be to grant the private seed company the right to accept royalty payments on a particular crop or crop mix. The payments could be adjusted according to yield and at least in the early stages subsidized by the government in order to encourage their adoption by the nation's farmers. This raises the question as to how much the government can afford to spend on an assured food supply. The question might better be asked by considering how much we can afford not to spend.

The agri-chemical companies who sell the fertilizers and pesticides would likewise appear to be poor candidates for promoting cropping systems that reduce the sales of their products. How they would be involved does require a stretch of the imagination, but perhaps instead of paying them for applying "medicine," much of which has harmful side effects, pay them for contributing to the maintenance of soil health and balance. Nutrients will have to be added but why should the nutrient and pesticide bill be based on quantity alone. It is in the spirit of the recent emphasis on Integrated Pest Management to recognize that species mix is automatically a chemical mix and if that chemical mix discourages insect and pathogen spread, the organizations and individuals responsible could be rewarded. The entire idea is somewhat like paying a doctor a fee while the individual is healthy with payments ceasing or slowing when an individual is sick. In our increasingly service-oriented economy, "package plans" are sold more and more.

8. Describe a plausible scenario . . . (continued)

This is not a promotion of agri-chemical involvement and the burden of defining their role in the development of a sustainable agriculture should be on their shoulders and not on the shoulders of the rest of the people in a free market economy. But we should not write off the private seed companies or the agri-chemical industry before they are given a chance to show how they can fully participate in a sustainable agriculture.

The USDA is an organization that can change its direction as often as every four years. However, given the nature of bureaucracy, there are numerous individuals who can continue to promote something they believe in even though the categories for funding may, for all practical purposes, disappear on paper. This organization has the greatest potential of any in existence for defining the mission for a sustainable agriculture and if it is decided internally, such an agriculture is appropriate, the machinery is there to give it the necessary emphasis and financial support.

Private research agencies perform tasks very well when they are clearly defined and of a routine nature. Many of the biochemical studies and much of the cytogenetic screening (see budget sheet) could be done by them.

We are apprehensive about both National Science Foundation - Research Applied to National Needs type programs and the U.S. Department of Agriculture. Probably the most competent of all would be the National Laboratories though the nature of their work does not lend itself to the type of research considered here. The most ideal situation would be the establishment of a mission oriented agency such as NASA.

9. Relate the potential productivity of this technology to the biological limits of crop yield, as discussed by L.T. Evans in "The Natural History of Crop Yield" (In American Scientist, Vol. 68, pp. 388-397, July-August 1980).

We think this question can be better considered at a future date. We don't believe enough information is available on these wild perennials to make the necessary comparisons.

10. How do current government policies affect research and development on this technology?

Government has traditionally responded to the direct interests and needs of farmers so long as there is some indication of ever-increasing yields. Research has been oriented to high yield even when that has meant the demise of small farmers and the growth of corporate farms and a huge agri-business establishment. It is unlikely the emphasis will change when one considers that food exports are a major way of softening our mounting balance of payment deficit. In 1980, the U.S. is expected to sell $40 billion worth of agricultural products which pales by comparison to the $83 billion we will pay for foreign oil.

This history, in which the emphasis has been on the bottom line, is partly the consequence of the fact that the time frame of too many politicians has been "until the next election." We would hope, however, that our leaders would see the long-term economic sense of a truly sustainable agriculture and allocate substantial funding to the project envisioned and promoted here.

What minor changes in government policy would enhance development of this technology?

Future policy considerations will be critical of the adoption of this new agriculture. Agri-business could be threatened for seed companies could drastically decline if annual crops are planted only on the 48 million acres of bottom land. Fertilizer and pesticide companies will experience reduced sales. Farm equipment, including irrigation will decline. These economic interests will have good reason to push for policies which give traditional crops an edge over the perennials. Inequities could come in the guise of concern for fair treatment. For example, government subsidy of energy, across the board for all farmers, whatever the reason; assured food supply, sympathy for their economic straits, etc., could slow the adoption of perennial polyculture. The corn field, in such a system of subsidy, will not have the higher energy cost subtracted and thereby gain unfair advantage as a competitor against the lower yielding, but less energy expensive perennials.

We are confident that with no subsidy any particular field could compete in dollar return, after adjustments have been made for lower energy input, lower fertilizer application, reduced pesticide use, reduced equipment cost due to reduced machinery use in seed bed preparation, planting and cultivation, reduced soil loss and reduced labor.

If any field is to be subsidized, it should be the perennial polyculture which experiences less soil erosion, less chemical contamination and which consumes less fossil energy.

Task	Professions Best Suited	Fund Dispensing Agents		Land Grant Univ./ Experiment Stations	Colleges/Univ. and other Educ./Research Organizations	Private Seed Companies	Contract Research Agencies	Ten year budget in $1,000										
		N.S.F.-R.A.N.N.	U.S.D.A.					1	2	3	4	5	6	7	8	9	10	
1. Species inventory a. taxa judged to have high seed yield potential	Field Ecology Biosystematics	100%		25%	75%			500	250	100	75							
b. taxa to be incorporated into inter-specific or inter-generic crosses to combine certain virtues	Taxonomy Range Agronomy		10%* 90%	80%	10%							50	50	50	50	50	50	5,125
2. Natural History Profile for each Candidate .species range .habitat .close relatives .plant and insect associations	Field Ecology Taxonomy Economic Entomology Plant Pathology	60%	40%	50%	50%			2,000	1,500	300	100							
3. Review and Investigation of Native Ecosystems where Agriculture is Now .Purpose being to develop a vision of future vegetative structure similar to what nature had before white settlement	Plant Geography Ecology Taxonomy	90%	10%	40%	60%			1,000	500	100	75	50	50	50	50	50	50	1,975
4. Living Assembly of candidates in Regional and Sub-regional Herbaries (Herbary Development)	Field Ecology Field Technician		33%* 67%	33%	33%				750	1,500	1,750	1,900	1,900	1,400	1,400	1,400	1,400	13,400
5. Biochemical Studies .nutrient value of seeds .amino acid profile .insect & Pathogen resistance .palatability	Biochemistry Plant Physiology	60%	40%	10%	10%		80%		500	2,000	2,000	1,000	1,000	750	750	500	500	9,000
6. Cytogenetic screening .Determination of chromosome races within taxa .Screen for peculiar meiotic configurations	Cytogenetics Cytotaxonomy Biosystematics	75%	25%	30%	50%		20%		500	1,500	2,500	3,000	3,000	2,000	2,000	1,500	1,500	17,500
7. Resource Allocation Studies .How and where photosynthate is allocated to different plant parts	Physiological Ecology	80%	20%	40%	60%					1,000	2,000	2,000	1,000	75	25	25	25	7,500
8. Wide crosses and new taxa establishment	Biosystematics Plant Breeding	60%	20%* 20%	50%	50%					1,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	15,000
9. Breeding and analysis of current and new species	Plant Breeding Quantitative Genetic Analysis	30%	20%* 50%	30%	25%	25%				500	1,000	1,000	1,000	2,000	2,500	3,250	3,250	14,500
10. Polyculture Development	Ecology Plant Breeding	30%	20%* 50%	50%	40%	10%					500	1,000	2,000	3,000	3,000	3,000	3,500	16,000
																	Total	$100,000
																		(or $100,000,000)

*Indicates percent of money to be spent within U.S.D.A.

Background Paper No. 16

AN OVERVIEW OF MAJOR LEGAL AND POLICY ISSUES RELATED TO THE IMPACT OF TECHNOLOGY ON THE PRODUCTIVITY OF THE LAND

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August 1980

Office of Technology Assessment
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This background paper was prepared for the assessment "Impacts of Technology on U.S. Cropland and Rangeland Productivity." The views expressed are those of the author(s) and not necessarily those of OTA.

TABLE OF CONTENTS

INTRODUCTION

I. Background Developments Influencing the Use of Technology on the Land

- A. Natural Resource Limitations
- B. Increased Demands on the Land
- C. Human Motivations

II. Legislation and Related Programs at the Federal Level

- A. Protecting, Maintaining, and Enhancing the Land Resource Base
  - 1. Soil and Water Conservation
    - a. The Soil and Water Resources Conservation Act of 1977
    - b. The Great Plains Conservation Program
  - 2. Forest and Rangeland Management
    - a. The Forest and Rangeland Renewable Resources Planning Act of 1976
    - b. The National Forest Management Act of 1976
    - c. 1978 Legislation
  - 3. Public Lands Management
    - a. The Federal Land Policy and Management Act of 1976
    - b. The Public Rangelands Improvement Act of 1978
  - 4. Controlling Pests and Nonpoint Source Pollution
    - a. Pesticide Regulation
    - b. Nonpoint Source Water Pollution
- B. Programs Related to Increased Production Demands
- C. Institutions Affecting Human Motivations

III. Unresolved Policy and Legal Issues................................

- A. What Are the True Costs of Production and who pays?....................................
- B. Choosing Mechanisms to Secure Conservation Goals....................................
- C. Providing Support Services..............................

IV. Concluding Observations and Possible Issues for Further Investigation..

APPENDIX: Sources of Information....................................

INTRODUCTION

This background paper discusses some of the major national policy and legislative issues underlying and influencing the use of technology and its impact on land productivity. It has been prepared under OTA contract for use in the development of the OTA assessment: "The Impact of Technology on Land Productivity." The presentation is an overview, principally of the major Federal laws and the strategies they embody for conservation and long range land productivity. Further refinement of the overall assessment and the direction taken by its technical analyses will provide substantial guidance regarding topics needing additional attention in the policy and law segment.

Material for this paper has come from three sources: interviews with persons involved with activities related to the topic, some of the major government documents and other articles available on the subject, and some of the principal pieces of related legislation at the Federal level. A list of information sources is attached as an appendix.

It should be noted that in the process of collecting ideas and information for this paper, numerous comments and suggestions were kindly offered. While all were important, I have given most serious immediate attention to those comments specifically related to and manageable within the scope of this background exercise. Throughout the paper, I have included a sense of these comments where appropriate.

The paper is organized as follows. First, a brief review of some of the background developments involved with this assessment topic is included as context for the rest of the paper. Second is the principal section discussing some of the major existing policies and programs influencing the topic as reflected in current Federal legislation. The greatest portion of this section discusses Federal legislation enacted to maintain and protect a productive base for our croplands, forests, and rangelands. It also briefly notes some water pollution and pest control measures. Then, some of the institutional factors having an impact, though indirectly, on efforts to achieve and maintain a productive land base are briefly noted. Finally, attention is given to some of the continuing policy and strategy issues of which resolution is fundamental and crucial to achieving long-term land productivity.

Consideration was given to the suggestion that this background paper be a comprehensive inventory of Federal legislation and institutions involved, either directly or indirectly, with the question of technology impacts on long-term land productivity. This suggestion was balanced with other observations reflecting less immediate interest in an inventory, particularly since a number of useful and related inventories already are available from other government studies.* In light of these considerations and the need to produce some analysis of the topic as direction for future work, it was decided that existing inventories could adequately serve as background for this project, at least for present purposes. As the project develops, an inventory specific to this assessment might be compiled if it is determined useful.

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*Three such inventories are particularly recent: 1) "Agriculture: Soil Conservation and Farmland Productivity," Congressional Research Service Issue Brief No. IB80031, Washington, D.C.: Lib. of Cong. (1980); 2) Soil and Water Resources Conservation Act--1980 Appraisal Review Draft, Part I/Chapter 8 - Federal Laws, Washington, D.C.: USDA (1980); 3) Desertification in the U.S.: Status and Issues - Working Review Draft, App. K: Federal Legislation on Renewable Resources Conservation and Management, Washington, D.C.: USDA (1980).

I. Background Developments Influencing the Use of Technology on the Land

It is important to recall some of the broader forces and trends which are having a substantial influence on the use of land technology practices and their adequacy in meeting the nation's long-term productivity needs. It is these kinds of broader issues which provide the underlying impetus for, or opposition to, national policies and programs involving technology use and productivity goal-setting. Depending upon their influence, they may dictate the direction of legislation. These broader developments might be grouped into three sets of elements: growing natural resources limitations, factors adding new demands on the land, and human motivations to maximize net income on the land. The following paragraphs give very superficial treatment to these elements since technical papers may deal with them in some detail. They are included only as a self-contained reference for the legal discussion.

A. Natural Resource Limitations

As observed by the American Society of Agricultural Engineers Task Force on Environmental Qualtiy in a policy issues paper submitted to Congress:

> "Soil productivity is not a permanent asset, and it is a factor affecting the permanent economic welfare of the Nation. Productivity is affected by physical soil property deterioration, deficiencies in organic matter and nutrients, and the rate of soil loss by erosion."[1]

There is growing concern that U.S. productivity increases are being met with serious constraints from land, water, and energy. Land is being depleted and converted to other uses. According to the National Association of Conservation Districts' Executive Vice President, the two main causes of land productivity loss are soil depletion and farmland conversion.[2] Water supply and quality are receiving increased attention; competing uses are already raising questions of long-term water availability for agricultural irrigation, livestock, and forestry, particularly in water-short Western States.[3] Soil erosion has a direct linkage with water quality as nonpoint water pollution increases through greater amounts of suspended silt and chemical residues in the water.

Some have suggested that technology developments in the form of more productive crop varieties, better pest management, the addition of fertilizers, etc., which generally have increased yields over the short term, are masking the threat to our long term productivity caused by increased soil erosion.[4] Soil erosion has become a particularly serious threat to productivity, not only in the mere loss of topsoil but also in loss of valuable nutrients and expensive chemical imputs. Yet, there seems to be little consensus as to the relationship between yield and erosion, or the maximum annual soil loss that can be sustained short of adversely affecting land productivity (this has been termed the soil loss tolerance, or "T" value).[5]

It is apparent that the use of certain soil conserving technologies on the land can lessen soil degradation problems, especially soil erosion. According to the American Society of Agricultural Engineers, "(t)here are many examples of practices that decrease soil erosion while maintaining or increasing the level of crop production."[6] The task appears to be convincing producers to use these technologies and developing further technologies which maintain a high level of long-term productivity by minimizing degradation of the land resource base.

B. Increased Demands on the Land

While our productive resource base is being threatened with increased degradation, a number of factors are increasing demands on the land. Several articles have noted a range of demand increasing factors.[7] The conversion of farmland for urban and industrial development is already an issue raising attention in several circles, including the Administration, particularly the Council on Environmental Quality (CEQ), which with USDA is finalizing a National Agricultural Lands Study. Conversion of range and forest lands appears to be receiving somewhat less of a spotlight while threatening equally serious and potentially irreversible damage. Additional competition for land as well as water is being caused by increased energy demands for production of electricity and mining of coal and oil shale deposits.

Food and fiber production demands also are increasing due to a number of factors noted below:

1. increased per capita income in developed and developing countries has affected the kind and amount of food and fiber in demand - people want more quantity and quality;

2. reliance on agricultural exports for foreign enchange to help balance our international payments for petroleum and other imported items has put greater pressure on the U.S. to export more agricultural products to maintain the integrity of the dollar and for inflation control;

3. a new demand for biomass energy and gasohol production will put food, fiber, and fuel production in competition, adding greater pressure for short-term land productivity.

4. new interest in Congress, Department of Defense, and the industrial community for self-reliance in agriculturally-produced industrial products (natural rubber, waxes, resins, newsprint, adhesives, etc.) which are now being imported.

These demand-increasing factors also add pressure to bring into production additional acres, which usually are less productive, more fragile, and more susceptible to soil erosion. This further exacerbates the land degradation problem and raises costs of erosion control.

The U.S. productive capability to meet these foreseeable demands is linked with the technology used to increase yields. The choice of production technologies and soil conserving techniques used on the land will substantially determine the long-term condition of the land resource base.

C. Human Motivations

More than one commentator has observed that a major human obstacle exists to the use of soil conserving technological practices to protect the land from long-term deterioration. As concluded by Dr. John Timmons, Professor of Economics and Charles Curtiss Distinguished Professor of Agriculture, Iowa State University:

> "...(P)eople are most interested in increasing their net income over their respective planning horizons. This involves maximizing revenues associated with their production activities in using labor, capital, land, and their choice of technological practices."[8]

As another observer has remarked, the costs of modern farming added to inflation and expectation of more inflation have influenced the farmer to plant based upon a guess about prices. The 4 or 5 year rotation cycle is becoming a thing of the past. Immediate economic pressures do not encourage conservation investments with a long-term payoff. "If soil is not cutting immediately and dramatically into productivity, the farmer has practical reasons to take his $10 and let future generations worry about the depleted soil." [9]

II. Legislation and Related Programs at the Federal Level

This section is organized following the order of the three sets of developments noted above: growing natural resource limitations, demand-increasing factors, and human motivations. The discussion will focus primarily on Federal legislation which directly relates to maintenance and protection of a productive natural resource base in view of growing natural resource limitations. Then, some of the institutional factors involved with increased production demands and the human motivation to maximize net income are noted; the issues raised here will be for possible further investigation later in the project.

A. Protecting, Maintaining, and Enhancing the Land Resource Base

1. Soil and Water Conservation

Since the 1930s, the Soil Conservation program has grown in focus and service. Its primary emphasis has been on technical and economic assistance rather than on imposition of soil-loss restrictions. With the authorization of the Conservation Operations Program in 1935, the Soil Conservation Service (SCS) of USDA had the responsibility to encourage use of soil conservation techniques and the development of conservation plans at the local level. The Agricultural Conservation Program of 1936 provided some cost-sharing assistance to implement these soil and water conservation practices. These programs were voluntary. Participation was low and concern grew that these approaches to conservation were proving ineffective. Growing regard for the condition of the land resource base eventually led to the enactment of the Soil and Water Conservation Act of 1977, and a strengthened regional program for the Great Plains.

a. The Soil and Water Resources Conservation Act of 1977.

The Soil and Water Resources Conservation Act of 1977,[10] which has generated the Resource Conservation Act (RCA) process, has been a major piece of legislation in the soil and water conservation area. According to its legislative history, the program was in response to a recognized need for conserving and improving our resources, a resource appraisal, a better data base, and thorough planning. Its purpose was to provide a "mechanism where the Federal Government in conjunction with State soil and water conservation agencies, local land-owners and users, local units of government, and others concerned, can make informed long-range policy decisions with respect to conservation and improvement of our country's soil, water, and related resource."[11]

In enacting the bill, Congress reflected upon some of the changing policies since the early 1970s and the effects of those changes:

> "Until the beginning of this decade, agricultural policy has dealt primarily with the problem of managing surpluses in an effort to provide a financial stability and security--in other words, policy attempting to control production. This policy was compatible with participation in conservation programs. Now, the emphasis is on full production, using more available acreage of cropland to meet domestic and foreign demand. The all-out drive for production has involved greater exposure of land to soil erosion and a variety of other hazards which we must deal with in an effective and timely manner."[12]

The legislation itself is oriented in part to future needs. It declares as Congressional policy and purpose that the "conduct of programs will be responsive to long-term needs of the Nation."[13]

To accomplish this and other purposes, the legislation calls for a continuing assessment of the resource, the determination of a comprehensive national policy and set of priorities based upon a resource inventory, the development of a National Soil and Water Conservation Program, and a continuing program evaluation.

Much has been written about the massive and at times contentious RCA process underway within USDA to meet the mandates of this legislation. The work continues, to involving numerous agencies and individuals throughout the country. The program has received both good and bad press. Some criticize the information and recommendations being generated as self-serving to cover the mistakes of a bureaucracy which should have begun long-term planning 50 years ago. The Natural Resources Defense Council goes even farther by insisting that the Soil Conservation Service, the primary USDA implementing agency for these matters, is not the right agency to achieve conservation goals due to its conflicting production mandate.[14] Others are optimistic about the program process and its potential for good results.

I have collected numerous RCA materials and commentaries. The legislation's policies and programs in long-term planning, better resource data collection, and priority-setting are positive and important steps. A well-planned national program for soil and water conservation will go a long way toward guiding the use of technologies which restore and maintain the land's productive base.

The key, of course, is how these policies and programs will be implemented. Alternative means of implementation are being vigorously discussed within the RCA process, and have raised some of the strongest comments. These alternatives presuppose some fundamental policy choices on the kinds of controls necessary (whether compulsory or voluntary) and judgments called for to slow resource degradation and achieve conservation objectives.

Beyond these general observations, it may be somewhat premature and duplicative for this background paper to research detailed developments within RCA. Not only is the program doing natural resource inventories, it also is evaluating policies, laws, and institutions dealing with soil and water resources from the point of view of achieving national soil and water conservation goals. USDA lawyers are expected to formulate recommendations in the next few months for changes in legislation to meet the needs of the new program. It may be desirable to give this process a chance. I will keep track of the RCA legislative developments and timetable in case there are elements OTA might properly investigate or incorporate into its own assessment process.

b. The Great Plains Conservation Program

The Great Plains Conservation Program was created in 1956, and has been extended through September 30, 1991[15]. It authorizes the Secretary of Agriculture, who acts through the Soil Conservation Service (SCS), to enter into contracts not exceeding 10 years with owners and operators of land in the designated Great Plains area where erosion is so serious that the contracts are necessary for the protection of farm or ranch lands. This contract provides the producer cost-sharing assistance to install the conservation practices necessary in order to conserve, develop, protect, and utilize the soil and water resources.

This regional program is completely voluntary. However, each contract approval is based upon a plan of farming operations and schedules of proposed changes and conservation measures which the producer must furnish and agree to implement on schedule. The plan must incorporate "soil and water conservation practices and principles as determined by (the land owner or operator) practicable for maximum mitigation of climatic hazards of the area...."[16] It must include "practices and measures for (a) enhancing fish, wildlife, and recreation resources, (b) promoting economic use of the land, (c) reducing or controlling agriculturally related pollution."[17]

The purpose behind the legislation was to implement a program for rehabilitation of agriculture on the Great Plains so that the farming and ranching operations of the area would be progressively established on a soil and water conservation basis. The area specifically was chosen for its susceptibility to serious wind erosion. In 1961, amendments to the program extended contract authorization to land not in farming or ranching where the erosion was so serious that a contract was necessary to protect area farming or ranching.[18]

Proposed program amendments before the 96th Congress ranged from broad bills to repeal both time and funding limitations, to simpler measures to delete the provision which restricts contracts only to those counties of eligible States. The proposal which became law in June, 1980:

- extends through September 31, 1991, the period during which the Secretary of Agriculture is authorized to enter into conservation contracts (the authority was scheduled to terminate December 31, 1981);
- expands the scope of the contracts to include farms, ranches, and other lands, susceptible to serious water as well as wind erosion;
- increases from $300 million to $600 million the overall limitation on program cost (excluding administrative costs);
- increases from $25 million to $50 million the annual program payment limitation.[19]

In principle the Great Plains Conservation Program signifies an important Federal initiative to help rehabilitate the area's land resource base through cost sharing contracts between the government and farmer for implementation of conservation techniques. However, serious criticism has been leveled against the program with respect to implementation. In particular, a 1977 GAO report has charged the program with making unsatisfactory progress in alleviating soil erosion problems. Reasons cited for this claim include the frequent funding of projects that are locally popular rather than of highest conservation priority, insufficient effort to promote the program where the most critical erosion problems exist, and inadequate extension work to encourage producers to maintain grasslands on area highly susceptible to erosion rather than convert back to croplands once the contracts expire.[20]

A fundamental criticism raised about the program is that the amount of acreage being treated annually has generally declined since the early 1970s. The GAO report suggests that higher crop prices and crop disaster relief programs may be providing enough of a financial offset against the risk of excessive soil erosion to keep the farmers' voluntary participation down.[21]

Generally, the report concludes that the program is making slow progress in attaining its primary objective--to establish wind and water erosion control conservation measures on Great Plains agricultural land. It recommends that SCS better identify and provide assistance to the most serious conservation needs first, and encourage farmers through periodic contact to maintain permanent vegetative cover on highly erodible lands.[22] It also indicates that SCS concurred with the intent of the recommendations and had agreed to carry them out within its resource capability.[23]

2. Forest and Rangeland Management

Several pieces of forest and rangeland legislation were passed by Congress in the 1970s in an attempt to better safeguard the long-term productivity of the resource. As noted in the legislative history, their development was an outgrowth of Congressional awareness that the resources are not infinite, that better planning and management assistance for both the Federal and non-Federal lands was critically important to assure the present and future availability of these renewable resources, and that the Forest Service Organic Act of 1897 needed strengthening.[24]

a. The Forest and Rangeland Renewable Resources Planning Act of 1974

The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA) was viewed as landmark legislation finally requiring the Forest Service by statute to engage in long-term planning.[25] With its enactment Congress expected the better accumulation of facts for making its decisions on policy and program funding to more adequately meet future demands on our forests and other renewable resources.[26]

The RPA's major provisions include requirements that:

1. the Administration prepare and keep current a National Renewable Resource Assessment and a Forestry System Renewable Resource Program;
2. this Assessment and Program be submitted to Congress for review;
3. an annual progress report be prepared by the Administration.

These Assessment and Program requirements include the preparation of inventories of present and potential renewable resources, their uses, needs, and opportunities for investment. Priorities in these areas are also to be considered. The national forest system inventory is to be comprehensive, detailed and kept current as part of the assessment program by the Secretary of Agriculture. Furthermore, the Secretary is required to prepare and maintain land and resource management plans for the units of the National Forest System, and to coordinate these planning processes with other agencies and government levels.

The Act's scope is comprehensive and far-sighted. The National Forest System is defined to consist "of units of federally owned forest, range, and related lands throughout the United States, and its territories, united into a nationally significant system."[27] This integral system is to be "dedicated to the long-term benefit for present and future generations."[28]

The RPA assessment and programming mechanisms are intended to develop a logical plan for the future. The first assessment was to be presented to Congress in December 1974, the next, and each one thereafter, at the end of the decade. The intent was that each assessment would be used for a decade, but updated with new facts as needed. According to the principal sponsor of the bill, Senator Humphrey, the expectation was that:

> "(t)he assessment will provide a regular and comprehensive data base, on a multiple resource basis, that will enable the Federal Government to set a consistent course while enabling the States and the private sector to likewise consider short- and long-term factors in resource actions."[29]

The Programs to be developed from the Assessments are expected to describe in detail for each five year period what the Federal effort should be. The first Program was due December, 1975, to be updated no later than March 31, 1980, and by March 31st of each fifth fiscal year thereafter. In an effort to instill more long-range thinking and planning, the legislation specifies that this programming process shall continue for at least the next four decades.

In addition, the legislation sets the year 2000 as the target year:

> "...when the renewable resources of the National Forest System shall be in operating posture whereby all backlogs of needed treatment for their restoration shall be reduced to a current basis and the major portion of planned intensive multiple-use sustained-yield management procedures shall be installed and operating on an environmentally-sound basis."[30]

Taken in total, the RPA seems to be future-oriented legislation which provides solid principles for long-term planning and action. It provides for wise and orderly development of the renewable resources of the forests, range, and associated lands. Even its approach to appropriations is more long-range than customary. Frequently, legislative provisions do not specify amounts to be appropriated for future needs. Instead, a general provision is included authorizing the appropriation of such funds as are needed to carry out the Act, thereby leaving the annual appropriations hearings to debate the entire range of possibilities. However, the RPA provides better guidance for planning by authorizing that amounts not to exceed $20,000,000 in any fiscal year are appropriated to carry out the purposes of assessment effort.[31]

This Congressional innovation was vigorously opposed by the Administration as restricting Presidential flexibility and discretion in preparing annual operating plans and attendant budget requests.[32] Opposition has continued through the present 96th Congress during its oversight of RPA. The debate, essentially between the President's Office of Management and Budget (OMB) and the Congress seems to be whether such an appropriations section commits the President or serves only as a guide.

I note this budget issue primarily because it is reflective of a controversy not limited to RPA. These issues are being raised, for example, in the RCA process. They might apply to any legislative program which requires some long-range planning and programming. The rationale for designating some future budget range for programming seems valid, particularly within the framework of such programs as RPA and RCA. The RPA assessments, for instance lead to the building of 5-year programs of work. Such programs can be used to frame budget needs at least as guidance for annual oversight and appropriations hearings. It becomes increasingly difficult to plan long-term programs without some indications of the anticipated funding resources likely to be available, particularly since Administrative agencies must first go through OMB. In this regard, present appropriation procedures actually may be counterproductive to long-term planning and programming.

b. The National Forest Management Act of 1976

A major amendment to the RPA occurred in 1976 with the enactment of the National Forest Management Act.[33] While the RPA provided the philosophy and fact-finding basis for long-term planning, this amendment provided a more specific framework for developing and implementing management plans for the specific resources. It requires several sets of guidelines and criteria in relation to resource management according to principles of multiple-use and sustained-yield. The provisions are specific about the content of the management plans, the required kinds of regulations and the goals to be acheived. Management plans for a resource are to be developed in a manner which ensures consideration of economic and environmental aspects, and so that the effects of each management system "will not produce substantial and permanent impairment of the productivity of the land."[34]

Motivated by court decisions regarding the meaning of the Forest Service Organic Act of June, 1897, Congress included a clearer statement on timber management and production. Guidelines are provided for timber harvesting only where there will not be irreversable environmental or natural resource damage, and where such lands can be restocked within five years of harvest. Clearcutting is generally prohibited except under certain conditions. Timber sales from each national forest are limited to a quantity equal or less than that "which can be removed from the forest annually in perpetuity on a sustainable-yield basis."[35]

While the principal 1974 Act did not speak to what the National policy ought to be because that legislation was to develop the facts for a policy, these 1976 amendments were now able to declare:

> "It is the policy of the Congress that all forested lands in the National Forest System shall be maintained in appropriate forest cover with species of trees, degree of stocking, rate of growth, and conditions of stand designed to secure the maximum benefits of multiple-use sustained-yield management in accordance with land management plans."[36]

Following the pattern begun with the RPA, the National Forest Management Act added a funding provision, authorizing $200,000,000 to be appropriated annually for reforesting and treating lands in the National Forest System for the fiscal year beginning October 1977, and each fiscal year thereafter.[37]

c. 1978 Legislation

In 1978, three separate bills were debated and enacted to provide more complete coverage and better field management assistance for all forest and rangeland renewable resources, not only those in the

Federal system. The Congressional concern "that we as a Nation assure the present and future availability of the renewable resources of our forests and rangelands,"[38] remained a principal motivation.

The Cooperative Forestry Assistance Act of 1978[39] provided the authority to bring together in one statute several major programs in cooperative forestry assistance, particularly to non-Federal lands. It provides formal authorization to the Secretary of Agriculture to provide financial, technical, and related assistance to States, agencies, private forest land owners and operators, and other individuals. Assistance may include training, management assistance, developing technical information services, research dissemination, etc. The Act strongly focuses on field-level implementation and contains several provisions related to matters of technical assistance. Moreover, the Secretary is expressly authorized to carry out a program of technology implementation to ensure that new technology is introduced and new information is integrated into existing technology at the local level. The legislation is specific that all these efforts are "to complement the policies and directives set forth in the Forest and Rangeland Renewable Resources Planning Act of 1974."[40] This link to the 1974 Act highlights Congressional intent that technology assistance be related to long-term planning and programming goals for forest and rangeland renewable resources.

A second piece of legislation enacted in 1978 is the Forest and Rangeland Renewable Resources Research Act of 1978.[41] This Act calls for a comprehensive program of forest and rangeland renewable research and dissemination of the findings. Again, the Act is expressly "deemed to complement the policies and directives set forth in the Forest and Rangeland Renewable Resources Planning Act of 1974."[42]

Finally, in 1978 Congress enacted the Renewable Resources Extension Act.[43] A principal purpose of the Act is to increase through education the yield of forest and rangeland renewable resources from private lands. But it has broader implications. The legislation is particularly reflective of the progress Congress has made toward realizing the interrelatedness of all renewable resources and the need for a total resource perspective. As part of the Congressional findings, the legislation states that:

> "to meet national goals, it is essential that all forest and rangeland renewable resources..., including fish and wildlife, forage, outdoor recreation opportunities, timber, and water, be fully considered in designing educational programs for landowners, processors, and users...."[44]

Moreover, the Secretary is required to prepare a five-year plan by September 30, 1980, for implementing the Act. This plan, to be called the Renewable Resources Extension Program, is to contain several specified items, including brief outlines of programs for planting and managing trees and shrubs in shelterbelts--a provision in furtherance of a Congressional finding that "trees and shrubs used as shelterbelts protect farm lands from wind and water erosion...."[45] A Congressional recognition of the interrelationships of resources and the need to coordinate resource activities is further reflected in the directives for preparation of this plan. The Secretary is required to take into account the relative needs for renewable resources as identified in the Assessments undertaken pursuant to the Forest and Rangeland Renewable Resources Planning Act of 1974, and the periodic appraisal of land and water resources provided under the Soil and Water Conservation Act of 1977 (the Act generating the RCA process).[46]

As evidenced by these legislative developments, Congress has made progress toward mandating better planning and programming to meet the Nation's long-term renewable resource needs. Legislative language exists for good policy and management guidance to support the use of practices and technologies which will assure future availability of the resources. Guidelines are numerous for the development of regulations, procedures, standards or criteria as needed to manage the resource for long-range yields. Even principles of timber production provide more careful guidance and control.

The processes mandated by the Forest and Rangeland Renewable Resources Planning Act, as amended, have been underway since 1974. In accordance with the provisions of the RPA, the 1979 Assessment, 1980 Program, and the Statement of Policy required by the end of the 1970s were submitted by the Administration to Congress in June, 1980. In response, Congress prepared a White Paper reviewing the Act's intent, and evaluating the Administration's Assessment and Program development effort so far. The Congressional White Paper covers many aspects. In essence, the Congressional message remains that the basic goal is land stewardship. The paper declares that:

> "...the role of the Federal Government in managing the National Forests is to protect and enhance the land, and to provide goods and services from those lands to the Nation's people. But the first consideration must be the enhancement and protection of the land, both forest and range."[47]

Furthermore, while accepting the President's Statement of Policy as submitted, it recommended that the Statement be "amended in the period through 1985 to refine future goals so that the Nation's needs can be supplied in an economically, environmentally, and socially responsive manner from both public and private forests and rangelands."[48]

As can be seen from this White Paper and recent legislation, Congressional intent for resource protection, maintenance, and enhancement over the long-term continues to be declared and reaffirmed.

Obviously, the key is the follow-through taken to implement these policies at the local level.

And, again, it is with implementation that the most serious questions and doubts are raised. It has been suggested that I identify and review, where available, examples of government conducted or approved projects where there may be some challenge or controversy over agency compliance with the provisions of RPA. The activities related to timber production in the West were especially emphasized. One case has already been brought to my attention. The Idaho Wildlife Federation has brought suit against the Forest Service on the basis of non-compliance with several laws, including the National Forestry Management Act of 1976, when it has been claimed, in part, that the Forest Service is allowing timber harvest in a highly erosive area of central Idaho with the use of technologies that may aggravate the erosion problems further and harm downstream salmon areas.[49]

It may be useful to identify some of these cases, particularly with respect to the institutional capability or motivation of responsible agencies at the National, State, and local levels to carry out Congressional mandates. Ultimately, the degree of implementation achieved for these new forest and rangeland mandates may depend upon the influence and persuasion of the local level. The law by itself may well remain neutral at the local level, regardless of its policy and program potential, without some motivating base.

3. Public Lands Management

In recent years, Congress has enacted two major pieces of legislation dealing with long-term planning and management of public lands: The Federal Land Policy and Management Act of 1976 and the Public Rangelands Improvement Act of 1978.[50] These laws focus on the development of necessary programs on public grazing lands to halt further land deterioration and mark a significant step forward from their predecessor law, the Taylor Grazing Act of 1934. They give express policy recognition to the plight of the lands, mandate in-depth plans, and provide funds for on-the-ground improvements.

a. The Federal Land Policy and Management Act of 1976 (FLPMA)

The FLPMA was the result of Congressional concern over deterioration of Federal lands and over the numerous, often conflicting or antiquated acts, related to public lands. It has been called the Organic Act for the Bureau of Land Management (BLM), a principal agency managing public lands. Indeed, a major purpose, as expressed in the legislative history, is to give BLM enough authority to sufficiently carry out the goals and objectives of public lands established by law.[51] The complete Act has six titles. The provisions range from those which set out broad policies and types of BLM authority, to others related to rights-of-way in protecting wild horses and burros, management in the California desert area, and a study of BLM's wilderness land.

The FLPMA specifies that the Secretary of Interior has responsibility for long-range planning of public lands under the BLM's control. This responsibility involves these areas of activitiy: 1) preparing and maintaining a resource inventory of all the lands; 2) developing and maintaining land-use plans for all lands by tract or area; and 3) on lands designated during the planning stage as available for grazing, the development of management allotment plans.[52] The land-use planning activity is guided by nine directives, including a mandatory provision for compliance with pollution laws and standards, and a requirement to balance long- and short-term benefits.[53]

Again, (as with the legislation on soil and water conservation, and forest and rangeland resources) FLPMA requires preparation and maintenance of a comprehensive resource inventory. This, along with the requirement for allotment management plans on grazing lands, provides particularly significant tools for guiding land use on public lands. The plans which are developed by BLM are to prescribe the extent and manner of grazing in order to meet multiple use, sustained yield, economic, and other objectives set by the Secretary. They also are to prescribe the range improvement methods to be utilized.

b. The Public Rangelands Improvement Act of 1978

To strengthen the FLPMA grazing land program, Congress enacted, in 1978, the Public Rangelands Improvement Act (PRI). This Act authorized and substantially increased funds for restoration and improvement of Federal grazing lands. In its declaration of policy, Congress recognized that rangelands are still in unsatisfactory condition and may even decline further without more funds and management. It declared that such "unsatisfactory conditions on public rangelands present a high risk of soil loss, desertification, and a resultant underproduction for large acreages of the public lands."[54]

Congress found the remedy to be better management and more funds to be raised through fees collected from livestock grazing permits and leases on public lands. Fees had been charged previously, but they had been traditionally below fair market value. While surely generating some debate prior to enactment, the legislation came forth with a provision specifying that the fees to be charged shall represent "the economic value of the land to the user"; it then designated the base and formula to be used for determining the fair market value.[55] Furthermore, the Act mandated that over 80 percent of the funds generated shall be spent for on-the-ground range rehabilitation, maintenance, and the construction of range improvements.[56]

The policy direction and program authority, so far as provided in these pieces of public land legislation, have potential for substantial positive impact on long-term public lands management. But, again, one reaches the question of implementation of both the Federal Land Policy and Management Act and the Public Rangelands Improvement Act. For example, concern has been raised that political lobbying by strong interest groups, such as livestock interests, may be proposing legislative amendments as well as influencing BLM administrative decision-making to favor historic grazing interests and weaken implementation of these new public land policies. There also has been some concern expressed that movement is underway to exempt management of public lands from the environmental impact statement process and other mandates of the National Environmental Policy Act (NEPA). If, in fact, this movement is seriously underway, it reflects not only the power of some special interests but also the potential for a major set-back to efforts aimed at long-term planning and management of public lands. Generally, a NEPA exemption could eliminate an important tool in weighing alternatives and balancing the short- and long-term benefits and costs of an action on public lands where there are potentially serious environmental consequences (e.g., resource deterioration and long-term productivity loss). These may be interesting issues to investigate further.

As with the implementation of RPA, it also may be useful at some point to identify case examples of some of the recent major, and perhaps controversial, administrative actions taken pursuant to these new legislative mandates. A review of the issues involved, local-level interests, agency decisions, and challenges could provide a factual background for better understanding the on-the-ground strengths and weaknesses of the program.

4. Controlling Pests and Nonpoint Source Pollution

a. Pesticide Regulation

Pest control technologies used in the United States include both chemical and non-chemical technologies. While the percentage of total acreage treated with chemical controls may be relatively small, the total amount of chemicals applied is large.[57] The use of chemical technology on the Nation's land to control pests has increased dramatically in the last few decades.[58] The farming sector has become dependent upon the chemical industries for large amounts of inputs, placing greater demands on the farmer for cash income to meet these increased costs.

The use of insecticides, herbicides, fertilizers, and other chemical technologies requires careful planning and an understanding of their proper place and handling. Because of a growing concern over the lack of an adequate national chemical pest control framework, the Federal government assumed a more dominant role in pesticide regulation with the adoption, in 1972, of amendments to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) of 1947.[59] The 1947 Act regulated labelling and registration of pesticides sold interstate primarily for anti-fraud purposes. In contrast, the 1972 amendments set up a more sophisticated regulation system involving governments at the

Federal, State, and county levels. FIFRA was further revised in 1978[60] to expedite registration, require more cooperative efforts between agencies, ease problems faced by pesticide applicators, and for other purposes.

FIFRA establishes a structural framework for preventing pesticide abuse and the dangers which accompany it. In theory, a three-tiered system was created: the Federal Government, through the Environmental Protection Agency (EPA), promulgates policy and regulations on registration, labelling, and use; the States implement the regulatory program consistent with EPA standards; and the counties enforce the program.

Much has been written about this program and debates continue about its effectiveness. The focus on pesticide registration to safeguard the environment has been challenged. The assumption that EPA will detect unreasonably dangerous pesticides during registration has been questioned on the basis that the data may be old and faulty, in disorganized files, based on superficial safety tests, etc. It has been suggested that registration should be de-emphasized because of such defects and that regulations should focus instead on better restricting the use of any pesticides except when essential for crop production.[61]

Furthermore, application of pesticides depends upon local-level awareness and enforcement capability. This requires ability on the part of local-level pest control staff to advise on the best means of control and to properly evaluate applications and issue permits for use of restricted pesticides. Local staff have been criticized for lacking proper education and at times having affiliations with chemical companies. Generally, there is a need for better training and education of local-level advisors, (especially in some of the new possibilities for alternate forms of pest control), and the elimination of the chemical affiliations of the advisors where that exists.

Policy considerations concerning chemical technology use and its impacts on long-term land productivity go beyond the immediate discussion of FIFRA. Because of the push for increased production, there is always the danger that short-term decisions for enhancing pest resistance will be made whether or not they are justified in view of the long-term effects for the farmer or for society as a whole. Some of the modern pest control methods have been critized generally as creating pest resistance, secondary pest problems and hazards to the natural environment.[62] Alternate forms of pest control are receiving limited attention.[63] The existing pest control programs still seem to lack any policy or strategy framework for a concerted effort to develop and deliver integrated technological systems and institutional support mechanisms for pest control that address some of the longer-term concerns.

b. Nonpoint Source Water Pollution

The Federal Water Pollution Control Act (FWPCA) of 1972,[64] as amended, should be noted. It was the first Federal legislation to formally recognize the problem of nonpoint source pollution and to cite agricultural activity as one of the many diffuse sources of such pollution. In particular, one section of the FWPCA impacts directly on kinds of technological practices to be used on the land. Section 208[65] directs the development and implementation of area-wide water quality management plans. These management plans are to be designed to achieve the goals of the Act, including the complete elimination of pollutant discharge by 1985, where technically, economically, and socially achievable. More specifically, the plans are to identify and set forth procedures and methods for the control of agricultural nonpoint pollution sources and the means of implementing such controls.[66]

In this effort, the Environmental Protection Agency (EPA) has indicated that States should adopt, where possible, "best management practices (BMPs)."[67] As noted in a recent EPA report, "Alternative Policies for Controlling Nonpoint Agricultural Sources of Water Pollution," best management practices under section 208:

> "...are the control techniques that a State considers most reasonable and effective and which are suitable to local conditions at the time of implementation. Such practices include crop rotation, less intensive cropping systems, conservation tillage, and structural controls. It is significant to note that these best management practices are preventive measures--they are directed toward controlling soil erosion on-site rather than dealing with sediment after it has eroded."[68]

The planning process is to involve citizens in the planning and the design of control policies. The Secretary of Agriculture is authorized to provide technical and cost-sharing assistance to land owners and operators who agree to implement approved conservation plans to control nonpoint source pollution.[69]

The "208 planning process" has been under way since before 1978, at which time when detailed management plans and implementation schedules for the states were due. At some point, either with this OTA assessment or perhaps with an assessment related to water quality, further effort could be put into investigating the progress made to date with implementation of section 208 and related sections of the FWPCA. In addition, I have not gathered information of its local-level impact or feasibility. By now there surely is some experience regarding the ability of the program to guide technology practices on the land, using a quality standard for water. Model State statutes also have been inspired by section 208; it may be useful to compare some State approaches to this very complicated regulatory area.

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Topics B and C of this section have not been developed with any detail. They are introduced primarily to stimulate discussion about their relevance within the scope of this assessment and the usefulness of further investigation.

B. Programs Related to Increased Production Demands

According to a member of the President's Council on Environmental Quality (CEQ), "the supplies of our natural resources in the future and the demands placed on them will be influenced fundamentally by international factors."[70] This development is being increasingly recognized by both government and nongovernment sectors. Testimony recently has been presented to Congress to this effect.[71] A government-sponsored study prepared by the Conservation Foundation recently examined agriculture as a strategic resource both domestically and internationally. The study recognized the value of U.S. agriculture in the world food economy for such purposes as food power, foreign exchange, and food aid.[72]

As noted in the background discussion, increased per capita income in developed and developing countries, greater reliance on agricultural exports for foreign exchange, movement to greater energy independence through the production of biomass, and new demands for domestically-produced industrial feedstocks are all factors increasing production demands. The farmers themselves want greater markets, as witnessed by their strong and continued support for food and grain export programs. The foreign exchange pressure is particularly powerful. As Dr. Timmons from the University of Iowa has suggested, "if we are going to use agricultural resources to correct the deficiencies in our balance of payments, we are going to have to take a look at what that does to our soil resources, or otherwise, we will be treating them just like the OPEC countries are treating their oil".[73]

These conflicting national interests--the one to conserve the land base for sustained productivity, the other to increase immediate yields--have been exacerbated by the absence of a national policy framework and set of priorities within which decisions can be made to accommodate all variables.

Policies and legislation provide support for many programs directly responding to the increased demand for agricultural products. Some of these programs might be examined specifically in terms of their consequences for long-term productivity. Trade and export policies and legislation might be reviewed. The 1977 Food and Agriculture Act,[74] the country's major food and commodity legislation, might be examined particularly in regard to its commodity and price support provisions and their relationship to national and international demands.

Also, new energy legislation, particularly the new Energy Security Act of 1980,[75] and associated policies, should be reviewed in the context of new pressures being added to the land resource base. Pulling together data from USDA on projected future agricultural yield, Neil Sampson, National Association of Conservation Districts, has observed that "future pressures on the cropland base could be fairly severe, even without added competition created by the energy situation."[76] Now with the focus on biomass production, considerable pressure could be added to the land base. The new Energy Security Act signals a major commitment to biomass production by committing $1.2 billion through fiscal year 1982 for financial assistance to synthetic fuel projects using biomass energy sources.[77]

As these kinds of demands grow, it becomes increasingly evident that the country needs a national policy and strategy to integrate programs and decision-making. Demand variables and needs should be considered within a framework which will assure protection of our long-term production capabilities. This important area needs greater Congressional attention. It may be useful as part of the OTA assessment to identify and better delineate some of the fundamental and competing issues and trade-offs involved.

C. Institutions Affecting Human Motivations

As noted in the background discussion, resource-conserving technologies are available to lessen problems of degradation, and help maintain our long-term land productivity. But the human drive to maximize present net income is becoming an overriding consideration. Increasingly, the farmer is opting for short-term gain, leaving to future generations the negative impacts which might occur beyond his or her immediate planning horizon.

This motivation, added to the demand-increasing pressures noted above, build a strong case at the local level for leaving concerns about soil depletion and future productivity unattended. In spite of far-sighted Congressional policies and program guidance in soil and water conservation, and forest and rangeland management, local indifference or outright rejection makes the road to successful implementation long and hard.

Compounding and reinforcing personal motivations to maximize net income are institutions which influence people's behavior and precipitate more land degradation. In particular, such institutions as land tenure (including tenancy), credit, tax, crop insurance, commodity programs, price supports, market prices, etc, affect the daily decisions of people and the kinds of planning and practices they use on the land. Again, Dr. Timmons, University of Iowa, explained in testimony before Congress:

> "Tenants possess short term planning horizons which motivate them to emphasize immediate income. Also, their rental arrangements do not usually encourage soil conservation investments with a long term payoff. The small size of the farm frequently forces people to press the land for a living regardless of effects upon soil erosion. Landlords who are interested in short run returns on investment usually are not motivated to make long-term soil investments.
>
> "Pressures of credit and tax payments dictate that sufficient income be generated to meet these obligations regardless of effects on soil erosion.
>
> "Prices and costs as determined in the market do not always reflect all the costs associated with cropland products. Soil erosion effects on offsite water quality deterioration are seldom reflected in the costs and prices as determined in the market. Of course, the same is true of offsite benefits. If offsite costs of soil erosion are not included in producer costs or consumer prices, there is little incentive to reduce these excluded costs."[78]

These institutional influences often are supported by express policies and programs. Their effects on people's motivations to take certain actions should not be underestimated. If there is crop insurance to reduce the farmer's profit risks from crop failure, is it not more likely the farmer may cultivate more marginal areas and build in less diversification? If current market prices cannot support conservation technologies, is it not more likely the farmer may forego those technologies for immediate return?

It may be important to investigate these programs further, particularly where they are supported by legislation. It is in this regard, for example, that the Food and Agriculture Act of 1977 should be carefully and thoroughly examined. Provisions on emergency price supports, supply control, disaster relief, and commodity programs should be viewed in light of their affect on decisions of the producer. Credit institutions, such as the Farmers Home Administration, should be examined from the point of view of the policies behind such national credit programs. Who are the most likely participants for such programs and what possible incentives might exist for promoting practices that maintain long-term productivity? Similarly, tax programs may have consequences decisive to the kinds of practices adopted and investments made on the land. What consequences might certain tax incentives and disincentives have on how the land is used.

It is these kinds of issues that might be raised in a review of the impacts of such secondary institutions on conservation programs and goals.

III. Unresolved Policy and Legal Issues

In the process of collecting information for this paper, several fundamental and unresolved issues continued to surface. These are the kinds of far-reaching topics particularly appropriate for OTA's attention. The issues are briefly summarized below.

A. What Are The True Costs of Production and Who Pays?

As noted by a Conservation Foundation study, it is "fully apparent that present prices paid by consumers are not reflective of the true long term social costs of production — soil erosion, compaction, salinization, declining acquifers, water pollution, loss of wildlife habitat."[79] In hearings on agricultural production and environmental quality, Congress was reminded that in the end, the public will pay these costs, either as taxpayers contributing to public conservation programs such as erosion control payments to private landowners and operators, or as consumers paying higher food prices caused by declining land productivity.[80]

There needs to be a policy debate on how to organize national production on a sustained-yield basis so the true costs of maintaining the land can be valued into the product. The natural resource costs must be viewed in terms of conservation and energy efficiency, as well as other considerations, and these costs must be related to more than short-term benefits. The country will need to come to grips with the fact that true production costs need some social investment because of their present and future offsite value, and because the present producer cannot absorb all onsite costs for benefits derived after he or she is gone. Congress must decide by what means the true costs, once determined, are to be paid. OTA might provide the technical valuation of total production costs and options for passing these costs on.

B. Choosing Mechanisms to Secure Conservation Goals

This issue flows from the last. Once it is determined that a certain social investment is required, how will this occur and by what means will society be assured that the investment is properly used on alternative strategies for achieving the goals of a resource conservation program? Generally, the Congress must make some fundamental decisions on the strategies and mechanisms required to implement policies aimed at maintaining a productive land base and a sharing of total production costs.

These strategies need a national perspective for programs operated at the Federal level, and a State perspective for local-level implementation. Nationally, it is apparent that greater coordination and integration of strategies is needed between different Federal programs and agencies to minimize the possibility of conflicting goals or consequences. For example, if grain gets subsidized so that the farmer plants more for export trade, are the consequences for the land and the market what we want? Is price support legislation consistent with other Federal efforts to encourage use of conservation technologies? How does disaster relief assistance affect the farmers judgments about risks he may take with the land? How can Federal investments in housing and urban development be better planned so they are compatible, rather than in competition, with Federal programs to protect farmland around cities? Etc.

Next, Congress must make some basic decisions about the types of voluntary and mandatory mechanisms required to achieve its policy and strategy goals. As discussed above, there seems to be growing concern that voluntary programs for implementing conservation practices are falling short of their mark, in part because the farmer doesn't feel he or she can afford to be interested. In light of the consequences we all may face from misuse of the land, some mandatory programs may become increasingly necessary to guide the producer's use of the land for the public good. The hurdles to enactment of compulsory regulation are great. It has been noted that "until recently almost all regulation of agricultural land has been at the instigation of the farmers to preserve their industry. Very little compulsory regulation has been imposed from outside sources, even where the land has been ravaged by overgrazing, erosion, decimation of timber lands, eradication of wildlife, and destruction of waterways."[81]

For mandatory controls, regulations might be promulgated, for example, which set penalities for violating set water and soil erosion control standards.[82] As another approach, one observer has suggested that national policy might require "a contractural relationship in which all government subsidy programs for farmers are conditioned upon the farmer's commitment to a specific conservation program for his (or her) own farm."[83] This idea is not new; it already exists in a limited form for the Great Plains Conservation Program discussed above. Such an approach would expand this application to all producers on the land, farmers, foresters and rangeland operators. All government assistance, (tax and disaster relief, credit, price support, commodity participation, etc.) might be included. While the program would be theoretically voluntary, its broad application would touch almost all producers in some way. The underlying purpose would be to induce a majority of owners and operators of land to enter conservation programs, rather than the minority that now participate.

At the same time, there are possibilities for greater use of other voluntary programs to ensure that society shares the costs of conservation with the land-owner or operator. The Federal Government has several options for providing economic incentives to use conservation technologies. Tax credits, low interest loans, insurance, and other financial programs all would be important tools. Of course, there is the possibility of direct cash assistance to producers who need it to move into greater use of conservation technologies. These possibilities need analysis and debate. Congressional efforts to design effective and complementary strategies and mechanisms for better cost sharing and land stewardship should be encouraged.

A State and local perspective is also needed for national strategies. It is apparent that the success of national policies or legislative programs depends upon local-level support and capacity to participate. Congress has been reminded that one role of the State and Federal Governments is to support local governments that want to protect rural land.[84] This means, for example, that government programs in other sectors should not offer simultaneous services, such as the finance of sewers, roads, recreation, housing, etc., for purposes which will conflict with rural land protection. Rather, if necessa[illegible] States might be given Federal start-up funds to help local people with tax incentives and technical assistance to start conservation and land preservation programs.

Planning and zoning assistance grants might be provided to local governments when tied to strong local preservation and soil conservation provisions. Cost-sharing assistance might be expanded and linked only to highest priority conservation needs.

Any such strategy or incentive must recognize that land-owners and operators don't have a long-planning horizon of 50 years or more. Therefore, the Federal, State, and local levels must join hands to find the resources to do what the people need in each area to protect their land.

B. Providing Support Services

Comments about support services and availability of funds are interspersed throughout articles, testimony, and other information on this assessment topic. Everyone needs a bigger budget. Levels of funding frequently are blamed for program failures. Ultimately, annual appropriations and OMB maneuvers determine the resources of a program. For this assessment, however, care must be taken to keep the issue of funding in perspective with other more substantive issues. The fact is that legislative bodies react to crisis, not to future needs. Not until Congress and appropriation committees appreciate the substantive issues surrounding the Nation's land productivity crises will more funds be forthcoming. The substantive issues must be the primary focus.

Bearing this in mind, it is still worth noting a few support needs which have been raised in several articles and are particularly relevant to the present assessment. They are the need for better information at the local level and expanded education programs for the producer, and greater creative use of existing technologies.

In Congressional hearings,[85] it has been suggested that often farmers are not convinced that a certain soil-loss level is the limit for maintaining soil productivity. Some may not be fully informed about acceptable erosion control techniques or the economic consequences of these practices and investments.

If funding priorities were to be set, it would seem that education and information dissemination at the local level should be high on the list. This information should be available in a form useful to local decision-makers and citizens. Wherever possible, district conservation offices and other local extension resources should be used and strengthened for purposes of information dissemination and education. It has been recommended to Congress that education programs in soil conservation, now poorly funded, must, of necessity, be expanded.[86] Furthermore, education can become an economic incentive option in situations where producers are not adopting soil conservation practices that would be profitable.

It also has been proposed that we give higher priority to "learning to use our natural resources effectively and conservatively by adapting known principles and technologies in an imaginative way to existing ecological and socio-institutional circumstances...."[87] In a statement presented to Congress, Dr. Jan van Schilfgaarde, Director of the U.S. Salinity Laboratory, USDA, California, suggested that we could make progress with creative use of existing technologies, even though it might seem less glamorous than the experimental research in biochemistry, genetic engineering, etc.

As has been indicated previously, much more is possible with existing technology and resources than has occurred as yet. Existing technology is not being used or investigated to its fullest extent for conservation purposes. For example, there seems to be little data base for estimating the impact of widespread organic practices on productivity, farm income, and consumer prices.[88] This is not to say that complete immersion in organic farming is the way to go, or that investment in high technology must stop. It is only to note that rather than investing piecemeal in new technologies for short-term yields and problem-solving, the Nation needs some longer range game plan as to how its technological resources might be used and organized most benefically in light of growing limitations and constraints. There are several fundamental policy and institutional choices which need to be made regarding what kind of conservation achievement is needed to maintain long-term land productivity. When long-range goals are set and needs are defined within this context, investment in technology might be better guided within some deliberative framework.

A 1978 National Science Foundation study of water problems in arid and semi-arid lands concluded that the main water problems did not exist because of technical incapacity. Rather, the primary cause was related to institutional deficiencies in such areas as conservation legislation, drought contingency planning, and economic incentives to treat and recycle waste water.[89]

In essence, our land productivity problems underscore similar deficiencies. Some fundamental decisions must be made. The Nation is faced primarily with an environmental question: what is the quality and quantity of the land resource base essential to meet its long-term productivity needs, and what are the tradeoffs which will be made with other needs? How will the resulting costs be absorbed? Based upon these decisions, long-range goals and strategies can be developed. Institutional needs and mechanisms can be integrated. Programs of incentives and disincentives can be designed to support the long-range goals. Until such fundamental decisions are made, the country will continue to react piecemeal to its land productivity problems, with frequent conflicting institutional purposes and increasing risks to maintaining and enhancing a productive land base with any long-term success.

IV. Concluding Observations and Possible Issues For Further Investigation

First, in gaining a sense of this topic through article after article, I have been amazed at how much criticism about the past and little creative thinking about the future abounds in much of the analysis. There are always exceptions. But to varying degree, the frequent approach, particularly of commentaries and even some congressional material, is to trace the background of the problem, e.g., the "Dust Bowl" days for croplands, the same references to top-soil loss, changing demands, impending crises that no one is recognizing, unworkable or weak programs, ineffective agencies, lack of funds or commitment, and on and on. I don't mean to imply that the problems do not exist or are not grave, rather, that OTA must go beyond these themes to be useful.

How to go beyond I am not sure. There may be problems and gaps with the RCA and RPA processes, for example, but the framework is sound. The point can be made with some confidence that as these programs exist in principle, their policies, planning and assessment mechanisms are commendable. Many of the programs discussed in this paper are relatively new, in the midst of change, and presently undergoing intra-agency analysis, as well as congressional scrutiny. It already appears that one of the most serious problems is implementation, in spite of well-designed policies and program frameworks. For OTA's purpose it may be premature to dwell on too much detail with these legislative programs as formalized, at least until they become more established and experienced.

A second point grows out of reviewing so many materials. The technology impact on land productivity issue easily leads to questions about resource conservation laws and policies. Only infrequently is mention made of other programs--price supports, tax and credit systems, etc.—and their impacts. The links are rarely developed to the point of identifying actual individual and cumulative program consequences for conservation and long-term productivity goals. More importantly, few attempts seem to have been made to pull together some concrete analysis of specific strengths or weaknesses in these related programs for achieving long range productivity goals.

It is apparent that OTA's task is one of achieving balanced assessments which draw upon past experience and present fact, for future projection. A heavy burden exists to avoid unnecessary duplication by dwelling too heavily on the same types of analysis underway through other processes. At the same time, judgments must be made about the kinds of existing analysis which need strengthening, further review or support through endorsement. As reflected in many comments received while preparing this paper, it seems that at least two characteristics differentiate OTA's role from that of CRS, GAO, or other organizations which deal heavily with technical analysis. First, and primarily, OTA is distinctly future-oriented in the long-term sense in its assessment of the facts. Second, its orientation, because of its advisory panel structure, and contracting potential can reflect experience, facts, and professional judgments as gathered directly from experts, workers, and other affected sectors throughout the country. For OTA assessments to be of maximum value, it must preserve and pursue these perspectives.

Moving on to specifics for furthur law and policy analysis, the following possibilities might be examined:

1. Are there kinds of activities requiring mandatory controls vs. kinds which will succeed with voluntary programs over the long-term? The Conservation Program within USDA, implemented by the SCS, is a case in point. As suggested above, would it be more effective if all farmers and other landowners or operators were required to adopt conservation plans? Which

programs in each of the areas, croplands, forests, rangelands, are at a critical stage requiring nothing less than mandatory regulation, from a scientific or technical perspective? A technical examination of mandatory (or compulsory regulation) vs. voluntary possibilities and consequeces in a few critical program areas might provide useful background for Congress. Whether Congress then chooses to go the way of the recommendations is a policy determination within their scope.

2. How are State programs handling land conservation problems, and what innovative experience might some programs be gathering which could have useful application in other States or for national policy and programs? Some articles have been written on this, and I believe this area is particularly appropriate for integrating technical and legal thinking with soem creativity. I could spend additional time here to at least attempt to identify some practical options being tried by States for policy and implementation of land use and management controls or guidance at the local level. Such

experence might be gathered and analyzed to give Congress ideas of programs which eventually might be supported by their endorsement and funding. Iowa and Wisconsin are examples of two States doing something in this area; there may be more.

3. Are institutional mechanisms related to tax, credit, disaster relief, and price supports, to name a few, having impacts on conservation efforts, and if so, what and how substantial are those impacts? If there is a link between the operation of these institutional mechamisms and conservation programs, is it positive, negative, conflicting, etc. What changes might be effected to create more complementary results? This would be an important area to better understand.

4. Are other government programs indirectly at odds with conservation and long-term productivity goals? Some attempt should be made to better research the institutional forces supporting increased production demands (energy, export, trade, industrial feedstocks) in regard to their consistency or conflict with conservation programs and goals.

5. How does Paarlberg's book, Farm and Food Policies—Issues in the 1980s, relate to this assessment? I received this publication too late to review for this paper. But on initial

glance, I am interested in the timeliness and parallel focus of the book for the OTA assessment. It appears to be fundamentally future oriented. A review could lead to incorporation of any useful substantive material for Congressional follow-up, as well as factually-based challenges where appropriate. The book seems to be having an impact on several individuals I contacted.

6. Where examples can be identified, it may be useful to review some of the cases involving implementation of the Forest and Rangelands Renewable Resources Planning Act, as amended, and the public lands grazing programs: the major issues and interests involved with any controversial decisions, etc. This could serve as some basis for identifying a range of elements affecting implementation of policies and programs. The case mentioned previously, Idaho Wildlife Federation vs. Cutler, is one possibility.

7. An analysis might be made of the conservation and other related proposals before the 96th Congress. A computer print-out of related bills has been reviewed, but no detailed analysis of the principal bills has been made. This Congress is so close to the end of its second session that such a

review might be of rather short-term use. However, a review of the related legislation actually passed by the 96th Congress, after this session adjourns, could be conducted.

8. More time might be spent on the policy and legal options surrounding pest control. The relevance of this may ultimately depend upon the emphasis OTA gives to pest control technology in the final report. The OTA Integrated Pest Management Assessment might be incorporated where relevent. The tentative recommendations of USDA's recent Organic Farming Report might be related. The issue certainly has been worked over in Congressional hearings and other reports.

FOOTNOTES

1. American Society of Agricultural Engineering (ASAE) Task Force on Environmental Quality, "Agriculture and the Environment--The Issues, a Public Policy Issues Report" (hereinafter cited as "ASAE Report"), in Agricultural Productivity and Environmental Quality, Joint Hearings Before the Subcomm. on Natural Resources and Environment of the House Comm. on Science and Technology, and the Subcomm. on Conservation and Credit of the House Comm. on Agriculture, 96th Cong., 1st Sess. 455 (1979) (hereinafter the Joint Hearings cited as "1979 Hearings").

2. Neil Sampson, "Protecting Farmland: The Ethical Dimension," in the 1979 Hearings, Id. note 1, at 285.

3. See, e.g., Statement of Dr. Leo Eisel, Dir., U.S. Water Resources Council, before 1979 Hearings, supra note 1, at 63-65.

4. See, e.g., ASAE Report in 1979 Hearings, supra note 1, at 456.

5. See, e.g., John F. Timmons," Testimony on Land Resources, Soil Erosion, and Nonpoint Source Pollution," before 1979 Hearings, supra note 1, at 227 (hereinafter cited as "Timmons' Testimony"); and, Timmons, John F., and Amos, Orley M., Jr., "Economics of Soil Erosion Control with Application to T Values," paper presented at annual meeting of Soil Science Society of America, Ft. Collins, CO, August 8, 1979.

6. ASAE Report, in 1979 Hearings, supra note 1, at 457.

7. See, e.g., U.S. Department of Agriculture, Agricultural-Food Policy Review 1-7 (1977); Timmons' Testimony, supra note 5, at 228; S. Batie and R. Healey, "U.S. Agriculture as a Strategic Resource: The Past and the Future," 40-43, in The Future of American Agriculture as a Strategic Resource (Batie and Healy ed. 1980); Neil Sampson, "Energy: New Kinds of Competition for Land," presented at 35th Annual Meeting of the Soil Conservation Society of America, Dearborn, Michigan. (August 1980) (hereinafter cited as "Sampson's Energy").

8 Timmon's Testimony, *supra* note 5, at 226.

9. L. Grant, "Conservation Viewpoint--Speculators in the Cornfield," 34 *Journal of Soil and Water Conservation* 51 (March-April 1979).

10. Soil and Water Resources Conservation Act of 1977, Pub. L. No. 95-192, 91 Stat. 1407 (codified at 16 U.S.C. 2001, et seq. (1977).

11. H. Rep. No. 95-344, 95th Cong. 1st Sess. 7, reprinted in (1977) U.S. Code Cong. and Ad. News 3670, 3673.

12. *Id.*, at 6; U.S. Code Cong. and Ad. News at 3672.

13. 16 U.S.C. 2003(a) (1977)

14. T. Barlow, "Three-quarters of the Conservation Job Not Being Done," in *Soil Conservation Policies, An Assessment* (1979).

15. Pub. L. No. 84-021 of August 7, 1956, 70 Stat. 1115 (amending Soil Conservation and Domestic Allotment Act of 1935, c. 85, 49 Stat. 163), (codified at 16 U.S. C. 590 p)

16. 16 U.S.C. 590p(b)(1)

17. *Id.*

18. Pub. L. 91-118, 83 Stat. 194 (1969) (Current version in Pub. L. No. 96-236).

19. Pub. L. No. 96-263 of June 6, 1980.

20. Comptroller General of the U.S., *To Protect Tomorrow's Food Supply, Soil Conservation Needs Priority Attention--Report to Congress* 47-55 (1977).

21. *Id.*, at 53-55.

22. *Id.*, at 55.

23. *Id.*

24. *See*, generally, Sen. Rep. No. 93-686, 93d Cong. 2d Sess.(1974); H. Rep. No. 93-1163, 93d Cong., 2d Session (1974); Sen. Rep. No. 94-893, 94th Cong., 2d Session (1976).

These reports and other legislative history reprinted in Compilation of the Forest and Rangeland Renewable Resources Act of 1974, Sen. Comm. on Agriculture, Nutrition, and Forestry, 96th Cong., 1st Sess, (1979) (hereinafter cited as the "1979 Compilation").

25. Forest and Rangeland Renewable Resources Planning Act of 1974, Pub. L. No. 93-378, 88 Stat. 476 (codified at 16 U.S.C. 160 et seq. (1974).

26. See, 1979 Compilation, supra note 24, at 165-166.

27. 16 U. S. C. 1609 (a) (1974).

28. Id.

29. Statement of Sen. Humphrey, Excerpt from Cong. Rec. of Feb. 21, 1974, S2051-2071, reprinted in 1979 Compilation, supra note 24, at 92.

30. 16 U.S.C. 1607 (1974).

31. 16 U.S.C. 1601(b) (1974)

32. See, e.g., Department of Agriculture's 1973 letter to Sen. Comm. on Agriculture and Forestry in Sen. Rep. No. 93-686, 93d Cong., 2d Sess. 23 (1974), reprinted in 1979 Compilation, supra note 24, at 79.

33. National Forest Management Act of 1976, Pub. L. No. 94-588, 90 Stat. 2949 (codified at 16 U.S.C. 1600 et seg. (1976), as amended by Pub. L. No. 95-233 (1978).

34. 16 U.S.C. 1604(g)(3)(C) (1976)

35. Id. at 1611(a)

36. Id. at 1601.

37. Id.

38. H. Rep. No. 95-1183, 95th Cong., 2d Sess. 9 (1978), reprinted in 1979 Compilation, supra note 24, at 1060.

39. Cooperative Forest Assistance Act of 1978, Pub. L. No. 95-313, 92 Stat. 365 (codified at 16 U.S.C. 2101 et seq. (1978).

40. 16 U. S. C. 2101(d) (1978)

41. Forest and Rangeland Renewable Resources Research Act of 1978, Pub. L. No. 95-307, 92 Stat. 353 (codified at 16 U.S.C. 1641 et. seq. (1978).

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58. See, J. C. Headley, "The Economic Milieu of Pest Control: Have Past Priorities Changed," reprinted in 1977 Hearings, supra note 1, at 526-527.

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61. See, e.g., J. D. Huffaker, "The Regulation of Pesticide Use in California," 11 U.C.D. Law Rev. 273, 283 (Nov. 1978).

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73. 1979 Hearings, supra note 1, at 337.

74. Food and Agriculture Act of 1977, Pub. Law No. 95-113, 91 Stat. 913.

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76. Sampson's "Energy," supra note 7, at 8. In tracing energy developments, Sampson notes a reluctance by USDA, prior to 1979, to move into a national gasohol program due to the questionable impacts on the land. According to his analysis however, as foreign petroleum supplies became tighter and as farmers lobbied for new markets to give a much-needed boost to farm prices, the concerns about the land base seemed to dissipate, Id., at 18-21.

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Background Paper No. 17

RELATIONSHIPS BETWEEN LAND TENURE AND SOIL CONSERVATION

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December 1980

Office of Technology Assessment
U.S. Congress

This background paper was prepared for the assessment "Impacts of Technology on U.S. Cropland and Rangeland Productivity." The views expressed are those of the author(s) and not necessarily those of OTA.

Background Paper No. 17

RELATIONSHIPS BETWEEN LAND TENURE AND SOIL CONSERVATION

The separation of farm operation from landownership has long been hypothesized to affect soil conservation through tenure arrangements and accompanying landowner attitudes toward stewardship. The issue of resource control and attitudes toward soil conservation has resurfaced recently in the hypothesis that a larger, more corporate agricultural structure will have unfavorable consequences for soil conservation. If significant differences in soil loss can indeed be associated with particular resource control arrangements, this information could be used to develop and implement more effective conservation policies.

The objective of this report is to assess the impact of resource control arrangements on the soil conservation practices of U.S. farmers and landowners. Hypotheses about the impact of tenure and organizational structure on soil conservation decisions are reviewed and past research is assessed. National relationships between landownership and conservation management practices are presented and analyzed for policy implications.

FACTORS AFFECTING SOIL EROSION

Soil management decisions at the farm level have been analyzed in the context of maximizing expected net income over a planning horizon. The rational individual calculates the income effects of a proposed conservation program over time and compares these effects to his/her expected income over time without conservation measures. Within this framework, individuals sharing similar erosion problems may reach different conservation investment decisions depending on the length of their planning horizon and individual time preference or discount rates.[1] A lower discount rate and a longer planning horizon encourage conservation decisions by increasing the present value of expected net revenues and by allowing sufficient time to recoup conservation investments.

Resource control arrangements are among the economic and institutional variables that have been hypothesized to influence an individual's choice of a planning horizon and discount rate and thus investments in soil conservation. Hypotheses about the impact of resource control on soil conservation can be divided into two categories--institutional imperfections in land tenure arrangements and attitudes toward soil conservation under different resource control arrangements. Both sets of hypotheses conclude that separation of landownership from farm operations can discourage soil conservation.

Tenure can be defined as the relationship between owners and users of resources. In the case of land, various tenure arrangements have been hypothesized to hinder soil conservation decisions (Ciriacy-Wantrup, pp. 150-160). Year-to-year informal leasing arrangements can, for example, result in a short planning horizon and reduced conservation investments. Similarly, if the costs and benefits of conservation investments are not shared equitably between owners and operators, conservation decisions will be less likely. If rents are fixed, low income tenants may not be able to forego income to invest in conservation measures. The type of lease in effect, cash as opposed to share, has also been hypothesized to affect conservation decisions by landlords and tenants under certain circumstances.

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[1] A discount rate allows for the cost of using resources through time and varies with the relative weight given to receipt of income now as opposed to the future.

In addition to these types of tenure problems, it has been hypothesized that attitudes toward conservation may differ under different resource control arrangements. Landlords, particularly absentee landlords, it has been suggested, may have a short-term planning horizon and a strong preference for income now that will lead them to maximize current income at the expense of future soil quality and perhaps future income (Timmons, p. 6). This hypothesis has been extended recently to encompass the issue of "family" versus corporate ownership of agricultural land. Corporate owners, it has been argued, lack a conservation ethic and will behave as absentee landlords in maximizing current income at the expense of soil conservation (Bible).

Researchers have previously examined many of these hypotheses through studies in small, relatively homogeneous areas with similar soils, climate and topography. By minimizing changes in physical characteristics, management and ownership differences, if they exist, are identified more readily. Tenure problems and owner resistance to conservation were found to be prevalent on high erosion farms in a series of studies conducted in Western Iowa since 1947 (Frey, Held and Timmons, Blase and Timmons, Hauser). Leasing arrangements, in particular, were examined by researchers and conservation practices under crop-share leases were found to reduce the landlord's income (Jensen, et al.). In terms of attitudes, absentee landlords in the Corn Belt were found to be unaware that conservation measures would improve farm income over time (North Central Farm Management Reasearch Committee). However, because of the relatively small geographical areas studied, it is sometimes difficult to determine how representative these studies may be. Also, a disproportionate number of these studies have been conducted in only one region, the Corn Belt.

Recent data from USDA surveys allow an analysis of the impact of tenure arrangements on soil conservation from a national perspective. In addition, these surveys provide previously unavailable information about the impact of the organizational structure of landownership units on soil loss. In the remainder of this report, these data are presented and analyzed for consistency with previous studies. Implications for public policies to control soil loss are also discussed.

ANALYSIS OF DATA

Data for this analysis were obtained from a merger of the 1977 National Resource Inventories (NRI) conducted by SCS and the 1978 Landownership Survey undertaken by the Natural Resource Economics Division (NRED), ESCS, USDA (Lewis). The SCS/NRI provided basic data reliable at the state level on land use, land quality, potential cropland, and soil conservation. The Landownership Survey sampled owners of land where NRI data were collected, thus obtaining information on the landowner that could be tied to the NRI data on soil conservation and land use. Approximately 37,000 responses were obtained and utilized in this analysis.

To test the hypothesis that soil conservation differs under different land tenure and organizational structure arrangements, research was conducted to test for differences in mean erosion rates on cultivated cropland owned by different types of landowners (Lee). Erosion data from the NRI, estimated by use of the Universal Soil Loss Equation (USLE), were used to calculate mean rates of soil loss for landownership categories.[2]

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[2] The USLE is an attempt to quantify soil loss at a given site by assigning factor values to the physical and management variables present at a given location (Wischmeier and Smith).

F-statistics were then used to test the hypothesis that mean erosion rates are equal on acreage owned under different tenure and organizational structure arrangements.

The results of the analysis indicate that nationally there are no significant differences in mean rates of soil loss among various forms of land resource control arrangements (tables 1 and 2). Acreage owned by landlords and nonfamily corporations did not exhibit significantly higher rates of soil loss than that owned by full owner operators or sole proprietors and husband-wife ownerships. However, these data do not allow a determination of the relative importance of management and physical factors in achieving a given level of soil loss. If significant differences in land quality exist among landownership groups, management differences may be obscured. Since hypotheses about landownership and soil conservation are management oriented, an analysis was formulated to focus solely on management factors influencing soil loss.

Data for land in cultivated crops were partitioned into two categories—land with and without an SCS designated erosion hazard. Within each category of physical susceptibility to erosion, percentages of cultivated cropland with conservation practices in effect were calculated for tenure groups and organizational structure categories. Minimum tillage and residue management practices were selected as an indicator of conservation management as these practices are considered to be highly effective and have applicability across regions and most crops.[3]

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[3] Minimum or conservation tillage generally refers to all tillage systems, including planting directly into untilled soil, that have conservation of soil and water, energy, and labor as primary objectives. Crop residue management is the use of crops left in the field after harvest for protection or improvement of soil. As there is some imprecision in these definitions, local interpretations were made by SCS field staff.

Table 1--Mean rates of erosion on U.S. cultivated cropland by tenure groups

Tenure category	Acreage owned (percent)	Soil loss (tons/acre/year)
Full-owner operators	25.85	5.08
Nonoperator landlords	36.53	5.21
Part-owner operators[1]	37.62	4.75

[1] Includes several minor tenure classifications

Table 2--Mean rates of erosion on U.S. cultivated cropland by type of organizational structure

Type of owner	Acreage owned (percent)	Soil loss (tons/acre/year)
Sole proprietor	39.19	5.02
Husband-wife	38.51	5.30
Family partnerships	10.65	4.74
Nonfamily partnerships	1.36	4.64
Family corporations	4.11	4.47
Other corporations	2.46	4.99
Other	3.72	4.86

An examination of the data reveals only slight differences in the distribution of erosion hazard land among landownership groups. Further, after controlling for these differences in land quality, the relationships between landownership and conservation management were found to be similar for both erosion hazard and nonerosion hazard land. As illustrated in table 3, on both erosive and nonerosive land, part owners have the highest percentages of cultivated cropland with conservation practices in effect, followed by nonoperator landlords and full-owner operators.

In terms of organizational structure, nonfamily corporations appeared to be average in their adoption of conservation practices (table 4). The differences between nonfamily corporations and more traditional forms of organizational structure, such as sole proprietors and husband-wife ownerships, were slight on both erosion hazard and nonerosion hazard land. Family corporations and partnerships with family members have generally higher percentages of conservation practices in effect on both types of land than other structural forms.

These results do not appear to confirm hypotheses about the impact of the separation of ownership and farm operation on soil conservation. Neither attitudinal differences nor land tenure problems are apparent in this analysis of conservation management among landownership categories. There are several possible explanations for our failure to confirm traditional hypotheses. All involve fundamental differences between minimum tillage, a relatively new conservation practice, and the traditional conservation measures in effect when hypotheses about land tenure and soil conservation were originally developed.

Traditional conservation measures such as terraces, grassed waterways, or gully controls have been considered investments to enhance land productivity. Once undertaken, these investments are tied to the land. Under these

Table 3--Adoption of conservation practices on cultivated cropland by tenure classification and land quality

Tenure category [1]	Erosion hazard land with conservation practices	Nonerosion hazard land with conservation practices
	Percent of acreage	
Full owner operators	43.55	46.20
Nonoperator landlords	47.33	51.33
Part-owner operators	53.28	55.94

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[1] Several minor tenure classifications are omitted from this table.

Table 4--Adoption of conservation practices on cultivated cropland by type of owner and land quality

Type of owner	Erosion hazard land with conservation practices	Nonerosion hazard land with conservation practices
	Percent of acreage	
Sole proprietor	48.03	53.13
Husband-wife	45.03	47.32
Family partnership	51.58	58.93
Nonfamily partnership	46.37	53.18
Family corporation	56.56	55.38
Other corporation	47.03	51.27
Other	49.25	50.40

circumstances, the more separated landownership and farm operation become, the more obstacles leasing and other tenure problems pose for conservation investments.

Investments in minimum tillage technologies, on the other hand, are closely associated with the operator and can be very mobile. Equipment used for minimum tillage practices can be used by part-owners on their own and rented land. While capital costs vary regionally, machinery investments for minimum tillage are considerably less than the amount of capital required for such conservation investments as terraces. Thus, the obstacles imposed by the separation of resource ownership from resource operation become far less important when conservation decisions involve the tillage practices of the operator instead of land altering investments requiring cooperation between owners and operators.

In addition, attitudes toward minimum tillage and traditional conservation investments are markedly different. Minimum tillage has been promoted as an energy and labor saving practice, as well as a conservation measure. While investments such as terraces are acknowledged to be uneconomical, at least over a typical farmer's planning horizon, minimum tillage and residue management are regarded as effective cost reduction measures (Mitchell, Brach, Swanson). If hypotheses about short-run income maximization goals of absentee landlords and corporations are in fact true, one would expect these groups to have high adoption rates of minimum tillage and consequently reduced soil loss, whatever their conservation ethic might be. The data in tables 3 and 4 suggest that this could be the case.

Further research is underway to examine additional relationships between landownership and soil conservation. Adoption rates among landownership groups of conservation practices that are capital intensive and fixed in location are currently being explored. It is hypothesized that tenure problems will have an impact on these investments. Research is also in progress to assess the interrelationships between resource control variables and other landownership factors hypothesized to affect soil conservation, including income, age, and education.

POLICY IMPLICATIONS

These data suggest that public policies designed to encourage or discourage various forms of resource organization and control in agriculture would have little impact on soil loss in the United States. However, the results of our analysis do suggest that public policies could be used to encourage the adoption of soil conserving management practices. The appropriate public policy will depend on the type of conservation practices that are needed.

In situations where minimum tillage and residue management are appropriate and economical, research and extension programs for those landowners who are reluctant to adopt these practices may be sufficient. Our data suggest that full-owner operators and husband-wife operations have lower adoption rates of these practices than other landownership groups. A preference for cleanly tilled fields or an unwillingness to increase pesticide and herbicide usage as is necessary with reduced tillage may account for some of this reluctance. If so, these problems can be overcome by targeted education programs and additional research on pest management and minimum tillage technologies.

In other situations where costly conservation investments are appropriate, or where a lack of capital prevents minimum tillage machinery investments, cost-sharing may be necessary to encourage conservation management. Unless economic incentives exist, farmers and landowners will not adopt conservation practices that are not profitable.

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Background Paper No. 18

DATA BASE ON GROUND WATER QUALITY AND AVAILABILITY: EFFECTS ON PRODUCTIVITY OF U.S. CROPLANDS AND RANGELANDS

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September 1980

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This background paper was prepared for the assessment "Impacts of Technology on U.S. Cropland and Rangeland Productivity." The views expressed are those of the author(s) and not necessarily those of OTA.

Abstract

This paper describes the basic elements of ground water availability and quality and its affects on the productivity of U.S. croplands and rangelands. It documents that an insufficient ground water data base is partially accountable for the slow-paced ground water adoption in water resource planning of many agricultural communities throughout the country. The task of this paper is to stimulate greater understanding of the wide ranging interactions between agricultural technologies and ground water resources and their implications for the future.

A general assessment is made of: current ground water data bases on the federal and regional level; types of ground water measurements made; interval of data collection; impact of agricultural technologies on ground water; case by case synopsis of recent research findings on those impacts; effects of ground water availability on soil, climate, vegetation, and aquifer environments; constraints of regional and time series analysis; contraints of using ground water data to predict long term productivity; modeling method's function in simulation analysis; practical efforts presently used to predict technologies impact on ground water resources; effects of inadequacy of the ground water data base on government policies; and aggregated social and economic affects of ground water imbalance.

TABLE OF CONTENTS

Page

INTRODUCTION.. 1

GROUND WATER MARKET.. 1

GROUND WATER SUPPLIES AND AGRICULTURAL PRACTICES..................... 2

  Depletion.. 2
  Increase of Dissolved Solids....................................... 4
  Subsidence... 6
  Scope of Report.. 7

GROUND WATER DATA BASES.. 8

INTRODUCTION - WHO SAYS WE NEED MORE INFORMATION...................... 8

GROUND WATER DATA ON EXTRACTION, RECHARGE, AND QUALITY............... 10

  Catalog of Information on Water Data............................... 10
  Water Resources Review... 10
  Regional Aquifer System Analysis Program........................... 10
  Madison Limestone Project.. 10
  National Water Use Data System..................................... 10
  National Water Data Storage and Retrieval System................... 11
  National Water Data Exchange....................................... 12
  State Water Resources Boards....................................... 12

GROUND WATER DATA COLLECTORS... 13

GROUND WATER MEASUREMENTS.. 15

GROUND WATER MEASUREMENT INTERVALS................................... 16

GROUND WATER AVAILABILITY AND QUALITY FOR AGRICULTURE................ 18

AGRICULATURAL TECHNOLOGIES AFFECTING GROUND WATER RESOURCES.......... 18

  Irrigation Induced Problems of Depletion, Subsidence, and Salinity... 18
  Fertilizer... 20
  Pesticides/Herbicides.. 21

RECENT RESEARCH FINDINGS ON GROUND WATER CONDITIONS AND AGRICULTURAL TECHNOLOGIES.. 22

  Depletion.. 22
  Subsidence... 23
  Salinity... 23
  Fertilizer... 24
  Pesticide/Herbicide.. 25

Page

ADEQUACY AND COMPATIBILITY OF GROUND WATER DATA...................... 26

GROUND WATER DATA AND THE SOIL ENVIRONMENT........................... 26

GROUND WATER DATA AND VEGETATION..................................... 27

GROUND WATER DATA AND THE AQUIFER ENVIRONMENT........................ 28

GROUND WATER DATA: CONSTRAINTS OF TIME SERIES ANALYSIS AND REGIONAL ANALYSIS.. 29

- Ground Water Basins and Types of Aquifers....................... 30
- Geologic Structure and Climate.................................. 30
- Aquifer Boundaries.. 32

CONSTRAINTS IN THE INTEGRATION OF GROUND WATER AND CROPLAND DATA BASES IN PREDICTING PRODUCTIVITY.................................... 33

GROUND WATER MODELS SHOULD BE USEFUL TOOLS FOR TOMORROW.............. 35

PRACTICAL METHODS USED TO PREDICT CONSEQUENCES OF TECHNOLOGICAL IMPACT ON GROUND WATER RESOURCES..................................... 37

- Well Log Records.. 37
- Hydrogeologic Maps.. 39

CONSEQUENCES OF GROUND WATER DATA INADEQUACIES...................... 40

MISUNDERSTANDING GROUND WATER RESOURCES IN CROPLANDS - AFFECTS OF GOVERNMENT POLICY.. 40

MISUNDERSTANDING GROUND WATER RESOURCES IN CROPLANDS - AGGREGATE ECONOMIC AND SOCIAL EFFECTS... 42

1. INTRODUCTION

GROUND WATER MARKET

The nation's ground water resource supplies about 70 percent of the irrigation water for the 17[1] western states. Before ground water turns from the great provider of U.S. agriculture to the great polluted resource or the great depleted resource, the needs of ground water management need to be more effectively and loudly voiced.

Hidden beneath the land surface, in almost every part of the United States, is water that fills the openings in beds of rock and sand - called ground water. While studies of the U.S. Geological Survey indicate that more than 97 percent of the fresh water resources are located under the ground, a mere 23 percent of that supply is utilized in the nation's water supply. Yet why does public consciousness of its ground water resource seem buried right along with this supply? Is ground water underused because it is unseen? Is it because the trappings of surface water use, such as dams and lakes, are more visible, have more political appeal, and, thus, carry greater political clout? While these reasons for the laissez-faire attitude may or may not be applicable, the fact still remains that the costs of cleaning up surface water pollution increase while the higher quality, lower cost ground water resource is bypassed.

Attempting part of the persistent end run toward greater public recognition, National Water Well Association is associated with the publication of both the Journal of Ground Water and Ground Water Monitoring Review. Each of these publications numbers among a handful of journals focusing specifically on ground water management and provides the necessary professional dialogue within the ground water community.

Tapping the ground water resource as a readily available source of drinking water, half[2] the population in the country gets its drinking water -- either completely or partially -- from ground water supplies. As a high quality, low-cost source, ground water use grows at the rate of several percent each year, right along with the potential for contamination from agricultural pollutants. Memphis, Dayton, and Wichita completely depend on ground water for municipal supplies.

If all of the nation's rural households were to discontinue their use of ground water supplies, 96[3] percent of the households would be without water. This acute dependence on ground water is further demonstrated by the fact that 67 percent of all ground water is used in irrigation. When all the figures are added up, almost a quarter of all the water used in the U.S. is ground water.

GROUND WATER SUPPLIES AND AGRICULTURAL PRACTICES

Clearly, with ground water usage growing from 35 billion gallons per day in 1950 to an estimated 80 billion gallons[4] or more this year, the question "Can we allow agricultural practices to affect ground water?" is moot. We already have. The facts of ground water mining, salinity, and subsidence seem so self-evident in the ground water environment that they are ignored.

Depletion - In the long list of ground water trade-offs, we disregard the delicate hydrologic cycle and the finite ground water supply in favor of perpetuating the agricultural machinery of high productivity. And if it seems customary to find no one on the sidelines, except a few research scientists holding their ears in anticipation of the consequential environmental explosion, maybe it is because we are constantly redefining what dangerous levels in the ground water environment really are.[5]

A few decades back hydrologists termed the concept "safe yield" as aquifers in which pumping does not exceed natural recharge. As "necessity", especially in the arid western states, dictated a retreat from a hydrologic balance, the concept of safe yield changed. By the 1940s, safe yield was revised to include a few qualifications: use should not exceed recharge, lowering the water table should not induce exorbitant pumping costs, and lowering the water table should not allow inroad of poor quality water. In the last twenty years, the term has been abandoned by the U.S. Geological Survey.

Partial blame for accepting ground water imbalance as a status quo can be assigned to agriculture -- consumer of 30 percent[6] of the nation's water. Ground water extraction rates outpace replenishment by ten to one in some regions of the Plains states.[7]

In a 1978 national review, the U.S. Water Resources Council predicts a water crisis as "a clear threat by the turn of the century." Water depletion combined with pollution effects "threatens the very survival of the United States," reports the Council.

The abundance of these doomsday statistics and reports should signal more than a blase response when it is emphasized that for some regions, doomsday for ground water supplies may be today. In Iowa, because of acute shortages, proposals are now underway to prohibit ground water supply use for irrigation. In Nebraska, the ground water pinch is prompting officials to consider allocating available ground water by metering it in control areas of the Natural Resources District. In the first court conflict between different types of ground water users, the Nebraska Supreme Court held that an irrigator can be held liable for costs incurred as a result of disturbing a neighboring ground water supply. Even the future of the region producing one-fifth of California's crop -- the southern San Joaquin Valley -- is gauged as "uncertain in terms of water and energy" by the U.S. Department of Agriculture.

One of the most dramatic instances of ground water depletion occurs in the Ogallala Formation, a ground water region stretching approximately 1000 miles from Nebraska to Texas. The High Plains section of west and north Texas has seen severe and continuous declines in ground water[8] supplies. In fact, depletion has been so extensive, prompting such high pumping lifts, that it has compelled abandonment of once productive farm land or the return to dry land farm practices. The U.S Water Council blames this drop in ground water levels on decades of irrigation pumping coupled with boosts in recent domestic and industrial use.

The 93,500 wells pumping irrigation for Texas croplands, U.S. Geological Surveys find, could literally pump the state dry. While seven to eight million acre-feet per year of ground water are withdrawn, a negligible 150,000 acre-feet per year are replenished.

Increase of Dissolved Solids - An additional adverse by-product of intensive irrigation is an increase in salinity. The presence of salts in water is as natural as the cycle which cleanses them in the soil, as water proceeds through the earth and finally into the rivers and sea. However, when the natural salt balance is strained by the great volumes of the irrigation water load, salinity increases. If the 10 million tons of salt present in irrigation waters were removed annually, there would be enough salt to fill 1,933 box cars.

As the Colorado River winds its way past 1,400 miles[9] of farm land, its salinity increases twenty times as 700,000 tons of salt are contributed from surrounding irrigated land. This means a present bill of $53 million to be paid from a loss of crop yield and corrosion gain and a future, yet unpaid, bill of reduced soil productivity.

The threat to agriculture has been so ominous that some officials see large scale farm land abandonment as the only alternative. At a conference on Salt and Salinity Management, agricultural irrigation managers were told that it can be more cost effective to surrender cropland than to take the more costly corrective measures of installing expensive desalination plants.

In calculating the costs of increased salinity, the buck doesn't stop here -- or anywhere except in increased agricultural costs, because the cleanup is an ongoing process. For every milligram per liter increase, the Bureau of Reclamation anticipates losses of $230.00. By the year 2000, the Imperial Dam will have accumulated 1,160 milligrams per liter, or a whopping indirect cost of $266,800 per liter.

The pollution threat from salt is greatest in the western states, according to findings of the Soil Conservation Service. In the Colorado, Rio Grande, and San Joaquin basins, salinity levels have reached the nation's all time highs. They are so high they have the Assistant Secretary of Agriculture, Rupert Cutler, worried that current soil levels are going to bring irrigation farming in the West to a screeching halt. As ground water becomes depleted and degraded, farmers in the West will be forced to rethink their resource priorities. This could mean a conversion to dry land farming for western farming.

Subsidence - One of the most visible effects of agricultural practices on ground water occurs in land subsidence. When ground water has been excessively mined, the failure to shore up surrounding top soil produces ground failure. Conditions such as fissures or faults appear associated with a drastic lowering of the water table. Primary settings for subsidence occurrence of more than 3.3 feet tend to be in Texas, Arizona, Nevada, and California. These environments, rich in carbonate rocks, overlay unconsolidated deposits most susceptible to subsidence. As the ground water beneath the unconsolidated area is removed so is its buttressing power.

The areal extent of subsidence damage can range from a 30 foot fissure in the San Joaquin Valley[10] to a land depression of four feet in the Santa Clara Valley ground water basin. In the case of the Santa Clara Valley site, ground water overdraft took place from 1914 to 1969 paralleled by subsidence damage. When ground water extraction stopped, subsidence stopped.

In the San Jacinta Valley, subsidence of the greatest documented areal severity has occurred. Approximately 5,400 square miles of the valley's thriving cropland have subsided at the rate of 1.2 feet a year since measurements began in 1935. In some regions, subsidence approaches 28 feet where deep irrigation wells pump more than 1,500 acre-feet of water each year. Where subsidence is most intense in the southern and western parts of the valley, recharge rates are scanty.

In the Houston-Galveston area, where all municipal water supplies find their source in ground water, the Harris-Galveston coastal subsidence District was formed[11] to monitor subsidence conditions. Prior to the initiation of ground water pumping in 1943, subsidence measured just over one foot. From 1943 to 1975, subsidence jumped to as much as 7.5 feet. Alternative water supplies were secured by the District, alleviating significant ground water withdrawal in 1977 and 1978.

SCOPE OF REPORT

One issue in the ground water-agriculture dilemma seems clear. If we continue to opt for regional ground water imbalance pressed by economic exigencies, we are drawing on the account of an unreplenishable resource which will produce an overdraft for the future generation. In weighing the sensitive series of trade-offs involved, the most valuable asset we can have at our fingertips is an abundance of current and specific data on ground water conditions.

For this reason, the task of this paper is to offer a generalized overview of the ground water-agriculture problems and outline the ground water information network which can assist in the answers.

2. GROUND WATER DATA BASES

INTRODUCTION - WHO SAYS WE NEED MORE INFORMATION

The overall need for ground water quality and availability data can probably be accepted as a truism. Throughout ground water assessment literature, the call has been for more extensive ground water data bases. In testimony after testimony in Nonpoint Pollution and Areawide Waste Treatment Management Program hearings before the House Committee on Public Works and Transportation on July 11-12, 1979, participants maintained inadequate or insufficient data was available to provide answers on nonpoint pollution impact upon agricultural users of ground water resources.

In appraising the status of ground water in a June 1977 Report to the Congress, the U.S. Comptroller General called for more detailed geological and hydrological data on aquifer systems to insure proper ground water management. To avoid or minimize ground water depletion, decision makers need to know the response time and capacity of specific aquifers. Since degradation can easily go undetected until it reaches crisis dimensions, adequate monitoring and analysis systems require responsive data bases.

According to President Carter's directive of July 12, 1978 and subsequent Executive Order 12113, Independent Water Project Review of January 4, 1979, during the planning of water resource projects, all Federal planning agencies are required to study ground water implications, pinpoint potential problems, and suggest alternatives to minimize ground water effects. As part of this executive focus on ground water, a Ground

Water Supply Task Force will assess available data to determine the extent of ground water mining.

With the spotlight on an expanded ground water data base, the U.S. Geological Service reported that ground water information needs were being meagerly satisfied. In its 1973 budget justification, USGS estimated data access at five percent for subsurface waste storage, 40 percent for resource appraisal, and 20 percent for systems studies.

USGS reports stress that a major push in ground water research will have to be made if ground water reservoirs are to assume a role in an inclusive water development program. Because aquifer rates of extraction/replenishment and water quality status are in flux, USGS points out the ground water monitoring and analysis system must adequately reflect the need for currency to effectively manage and develop the ground water resources. To date, USGS terms available information inadequate for applying hydrologic principles and discerning area occurrence of water.

The Office of Water Data Coordination (OWDC), as part of the Geological Survey's Water Resources Division (WRD), coordinates water data acquisition activities of the 29 Federal agencies involved in spending $10 to $12 billion annually in water programs. In its 1979 survey of stations conducting water monitoring, Regional Plans for each of the 21 Water Resources Council (WRC) planning regions specified categories of water data deficiency. Serving as a nucleus of federal water data acquisition and information, OWDC concludes in its synopsis that, "A widespread need exists for more detailed information on the quantity and quality of ground water resources."

GROUND WATER DATA ON EXTRACTION, RECHARGE, AND QUALITY CATALOG OF INFORMATION ON WATER DATA

Ten years ago, the U.S. Geological Service recognized the critical need for mapping ground water quality and quantity in the 21 WRC regions. Eight years and twenty-one volumes later, the USGS had completed the lengthy task--the first national compendium on the quality of ground water resources. The Catalog of Information on Water Data precisely delineates ground water data in ten reporting categories of physical data, 14 categories of chemical data, three categories of biologic data, and four categories of sediment study. This ground water inventory is tabulated from ground water withdrawals from approximately 1,500 wells.

Water Resources Review - Each month USGS updates ground water conditions in the periodical Water Resources Review. A narrative synopsis of ground water levels in a region by region overview are available.

Regional Aquifer System Analysis Program - Spurred by the demands placed on ground water in the central and western states by recent droughts and energy development, USGS implemented the Regional Aquifer System Analysis Program in 1978. The task of this program is to assess the nation's major regional aquifer systems, to describe the magnitude of fresh and saline ground water resources, and to determine both hydrologic and geochemical traits as well as the extent of hydrologic interaction. To predict the effect of future development and rates of extraction, simulation models of each aquifer system are being employed.

Madison Limestone Project - Further studies on long-term and short-term ground water withdrawals in regions of Wyoming, Montana, North

Dakota and South Dakota, and Nebraska were initiated by USGS in 1976. The goal of this project is to forecast the effect of proposed large-scale water withdrawals required with the development of energy resources in the northern midcontinent region.

National Water Use Data System - Still in its infancy, this cooperative state and federal program was implemented by the Geological Service in an effort to disseminate data about water usage, withdrawal, and return of water. As of July 1, 1979, field data collection activities are ongoing in 15 states. The lesser known withdrawal/return data base has been underway for just one year and contains aggregated data by county and state.

National Water Data Storage and Retrieval System (WATSTORE) - Here, in WATSTORE, the Geological Survey operates its 54 numeric data base systems. Since 1971, information from tens of thousands of ground water quality wells throughout the United States and its territories has been stored in a Daily Versus File, containing 118 million[12] daily values including ground water levels. A Water Quality File, with the capacity for 1.4 million analyses of water samples, maintains data on more than 200 different constituents of chemical, physical, biological, and radiochemical ground water properties. Information for more than 600,000 wells can be accessed on the Ground Water Site Inventory File. Data retrieval provides inventory data concerning geohydrologic traits, well construction history, water temperature and water level of wells and springs. The file is designed to permit 209 data elements.

National Water Data Exchange (NAWDEX) - An interagency program managed by the USGS NAWDEX was founded in 1976 to improve water data availability and water handling needs of 30 federal, seven interstate, 37 state, and 19 local government agencies, 30 academic and 17 private organizations, and two foreign affiliates. For ground water, this means an expansion of the ground water data base stored in EPA's STORET which indexes water quality at an estimated 200,000 ground water sites. The most widely recognized data base in STORET is the Water Quality File (WQF), comprising up to 1800 water quality parameters. A diversity of water data is also available from data systems of the 147 participating NAWDEX member organizations.

State Water Resources Boards - In addition to federal monitoring, a number of state water resources boards process local ground water data on levels, pollution sources, acres irrigated, water use in the municipal, industrial, and recreation sector, and numerous other parameters.

Quarterly publications such as the Kansas Water News detail the information-collecting activities of the five ground water management districts in Kansas. The Oklahoma Water Resources Board produces an annual summary of computer tabulations delineating specific ground water use by county. In the newsletter, Texas Water, produced by the Texas Department of Water Resources, ground water levels of observation wells are compiled and graphed on a monthly basis. The ground water conditions and issues of the High Plains are regularly treated in the monthly publication The Cross Section produced by the High Plains Underground Water Conservation District based in Lubbock, Texas.

GROUND WATER DATA COLLECTORS

Although the U.S. Department of the Interior is charged with the official role of acquiring all basic data on ground water in some 21,000 USGS monitoring wells, this does not inhibit the development of water-data program studies in other branches of the federal government with ground water quality concerns.

As part of both the Watershed Development study and the Conservation and Use of Land and Water Resources and Maintaining Environmental Quality, the Agricultural Research Service (ARS) relies on extensive on-site monitoring of ground water quantity and quality combined with climatic and environmental elements. About 215 individual study sites are used by ARS to deliver information for on-going programs in water quality investigations related to non-point source pollution, to water quality and quantity studies of disturbed lands. Programs are also anticipated in the area of ground water recharge. Hydrologic data generated by ARS are stored by its in-house hydrologic data bank operated by the Hydrologic Data Laboratory and interfaced with NAWDEX.

Under a cooperative arrangement with the Geologic Survey, the Corps of Engineers play a vital role in updating ground water quantity and quality information at about 2500 sites. However, aside from the ground water data funneled to USGS, the Corps of Engineers operates an additional 2500 research sites and a water data research laboratory. Long-term needs projected by the Corps call for an expansion of the ground water data collecting network and increased automation of data collection and analysis to keep pace with increased ground water information demands.

Although the Bureau of Land Management is not a water oriented agency, water resource information, including ground water resources, plays a valuable role in preserving water on the 470 million acres of public lands it manages. With the assistance of a number of federal agencies including USGS, the Bureau conducts inventories, analyses, and interpretations of the occurrence of ground water sites. As part of the Energy Minerals Rehabilitation Inventory and Analysis program, the Bureau operates a data collection network of about 250 surface and ground water stations in seven western coal states and Alabama. The program objective is to provide data on the rehabilitation possibility of federally leasable coal lands.

In conjunction with USGS, Bureau of Reclamation efforts to conserve limited water and land resources are demonstrated in the 17 western states. In the Southwest region, data collection has been initiated on the ground water study effects of the Raton Project in New Mexico. The lower Missouri region has been the focus of a recent Bureau of Reclamation's probe into ground water data in the Missouri and Arkansas River basins. In the Pacific Northwest, 1978 marked the beginning of the Bureau's five-year ground water collection project for the Columbia Basin.

The International Water and Boundary Commission collects data on ground water quality along the U.S.-Mexico border to insure proper execution of treaties between the U.S. and Mexico. Even with 142 collection sites, IWBC projects that additional information on ground water resources will be needed in fulfilling its long-range goals. Providing the complementary objective for the Canadian border is the International Joint Commission which gathers ground water data to aid in Commission activities.

GROUND WATER MEASUREMENTS

Because the basic component in supporting a ground water monitoring methodology is to provide guidelines for the needs of the prospective user, one type of measurement crucial to a policymaker might be totally ineffectual for a geologist. Thus, in assessing the kinds of ground water measurements from the point of view of agricultural effects, it would be most useful to use the USGS Catalog of Information on Water Data as a prototype.

Here ground water quality is outlined in terms of four traditional categories: physical, chemical, biologic, and sediment. Identified within each category are a selection of constituents: temperature, specific conductance, turbidity, color, odor, pH (field and lab), Eh, suspended solid in the physical category; dissolved solids, chloride, nutrients (nitrogen), nutrients (phosphorus), common ions, hardness, radiochemical, dissolved oxygen, other gases, minor elements, pesticides, detergents-MBAS, biochemical oxygen demand, carbon (total dissolved) under chemical data; coliforms and other micro-organisms as biologic data; and finally concentration (suspended), particle size (suspended), particle size (bed material) under sediment assessment. The list is an extensive one. Although there are an infinite set of potential pollutants in the biological and chemical categories, these constituents are an adequate sample to signal the presence of a pollutant.

The key question the agricultural user would ask of a ground water monitoring system is -- does it alert the user to changes in the soil zone, soil reactions, and ground water percolation, or to the presence of leachates and gases, and does it permit lead time for corrective action? Changes in the soil zone include from organic to inorganic, nitrogenous compounds to nitrate, and phosphorus compounds to phosphate. Similar effects, including denitrification, degradation of organic compounds, and nitrogen fixation, are detected by the Eh or pH measurement constituents. With the decomposition of solid wastes and the ensuing production of leachates and gases, the measurement constituents of color, odor, pH, hardness, turbidity alert the monitoring system to a contaminant presence. Given sustained agricultural pollution, percolation to the ground water would result in high TD5 NO_3, Cl, SO_4, and NA which would be pinpointed by USGS constituents -- dissolved solids and other gases.

In terms of precision and accuracy, for the results of agricultural pollution, the USGS constituents can capably detect quality trends and isolate and assess precise causes of pollution.

GROUND WATER MEASUREMENT INTERVALS

If a ground water monitoring program is to be successful, the frequency of review must be based upon ground water as a dynamic commodity. Ground water is influenced by both the natural hydrologic cycle and man-made causes. Data derived must enable the development of a predictive framework. Obviously, it would be unrealistic, unnecessary, and economically infeasible to call for a daily, monthly, or even quarterly measurement of all monitoring sites. Each aquifer must be gauged in terms of the demands placed upon it. An aquifer undergoing extensive development should be monitored more closely than an aquifer in an outlying region. In this case by case determination of aquifer monitoring, an accelerated frequency of review might be called for if the aquifer had experienced an immediate contaminant surface spill, if an intensive pesticide application had occurred, or if some surface disposal contaminant had been experienced.

Again, using the USGS as a prototype, all of its twenty-eight constituents for each of 21,000 sites are checked either continuously, seasonally, daily, weekly, monthly, quarterly, annually, or periodically. Each constituent seems to have an even distribution of review processes, from daily pH monitoring, to weekly color monitoring, to quarterly review of suspended solids. As specific knowledge of the problems of each aquifer monitoring site would be required to appraise adequacy or inadequacy of measurement intervals, it must be assumed that the review process is sufficiently fulfilling aquifer monitoring requirements.

3. GROUND WATER AVAILABILITY AND QUALITY FOR AGRICULTURE

AGRICULTURAL TECHNOLOGIES AFFECTING GROUND WATER RESOURCES

In recent years, U.S. agriculture has been able to feed the nation so well that it exported a surplus of $25 billion worth of farm products annually. But that surplus has taken its toll on our natural resources in general and on the delicate hydrological cycle in particular. Agricultural pollution alone is blamed for influencing two-thirds of all river basins in the U.S.

Irrigation Induced Problems of Depletion, Subsidence, and Salinity - With 40 million acres of irrigated farmland in the 17 western states, some states are straining the limits of their ground water supply and quality. In fact, the U.S. Department of the Interior notes parts of Nebraska, Colorado, and Kansas have crossed over that limit. Water is being withdrawn from ground water supplies in these states at a rate ten times faster than the recharge rate. Although warnings of ground water depletion are frequently being made, they are hardly new. Dr. Oscar E. Meinzer addressed the Convention of the American Association of Water Well Drillers in New York more than forty years ago on the consequences of rapid ground water consumption, warning that "We must guard against the depletion or spoiling of our extremely valuable underground reservoirs. Conservation and use of these natural reservoirs is one of our major national problems, and it is immediately urgent."[13]

As mentioned earlier, hand in hand with the irrigation induced problem of depletion goes the problem of subsidence. As agricultural development in most of the arid West has been supported by pumping wells, and as water levels are diminished on an average from 100 to 500 feet, the stress and compaction of deposits, assisted by the overdraft, results in subsidence. Joseph Poland, hydrologist with the U.S. Geological Survey, concludes after 25 years of subsidence studies that subsidence can only be halted by raising water levels substantially to avoid excess pore pressure in fine-grained confining beds.

It's irrigation practices like these that are causing officials to worry about depletion of soil productivity. But before any alarmistic conclusions are drawn that U.S. agriculture will go from bread-winner to standing in the bread line, let's consider irrigation effects on the ground water environment.

All waters contain a limited percentage of dissolved salts and minerals. When irrigation return flow percolates through the soil and past the root zone, the water is usually degraded. As percolation continues down to the zone of saturation, water is exposed to more of the saline features of the soil, and geological formations and greater salt accumulations find their way into ground water sources through leaching.

The region where this irrigation boom has produced the greatest ground water contamination bust is in the arid southwestern states, according to findings of Geraghty and Miller (1977). Ground water quality has degenerated from irrigation return flows in the Rio Grande basin of New Mexico and Texas. The Colorado River system has experienced such a rapid increase in saline concentrations that estimates place damages to the regional economy at $125 million a year (in terms of reduced crop yield) by the year 2000. Other areas victimized by irrigation flow include the Pecos River valley in New Mexico and Texas and the Arkansas River valley in Oklahoma and Arkansas. Broad-scale reports on degredation of ground water quality have also circulated targeting the San Joaquin basin in California.

Despite much pessimistic analysis of southwestern states, irrigation flow effects have not left the northwest untouched. Evaluations there claim the existence of more than two million acres of saline land. The valley of the Grande, Platte, and Arkansas Rivers of Colorado, the Yakima valley of Washington, Lorimer County in Wyoming, Rosebud County, Montana, the Snake River valley of Idaho, and the Columbia River basin in Washington all have documented irrigation flow problems. In parts of the Colorado River, the ratio reaches as much as a ton of salt per acre-foot of water.

Fertilizer - The 40 million tons of commercial fertilizer spread on the nation's soil last year have been the life's blood of agricultural productivity. But for ground water quality, it is another pollution threat. According to the U.S. General Accounting Office, heavy reliance on fertilizer results in an estimated one million metric tons of nitrogen discovered in ground and surface waters.

The use of nitrogen and phosphorus containing fertilizer is symptomatic of the current schizophrenia in agricultural practices and ground water resources -formerly benevolent activities assume malevolent results for ground water. The nutrients which enable a high-yielding crop enhance the nitrogen withdrawn by the crop in given instances. However, if the nitrogen provided by the fertilizer surpasses the crop nitrogen withdrawal, the potential for pollution arises. Surplus nitrogen will remain close to the root zone without substantial ground water. Ground water does serve as a transporting agent, carrying plant nutrients into streams, lakes, or aquifers.

There are conflicting reports on the effects of levels of pollution patterns in ground water settings as the result of fertilizer usage. Ground water discussion has centered around the resulting salinity increase and the quantum jumps in nitrate concentrations. In the Seymour water-bearing formation in Knox and Haskell Counties in Texas, jumps in nitrate levels of from less than 50 ppm to 165 ppm can be traced to fertilizer use.

Pesticides/Herbicides - The Soil Conservation Service reports that more than 1,800 pesticide compounds marketed in 32,000 various products will put an estimated 1.25 million tons on American soils by 1985. And five percent of that will reach the nation's waters. A 1970 Report of the Working Group on Pesticides cautioned that the potential for ground water contamination must be analyzed from the perspective of the properties of the pesticide, hydrological traits of the disposal area, and the volume, state, and persistence of the pesticide. For example, greater hazard occurs when high concentrations of pesticides are deposited near shallow wells or in regions of thin and highly permeable soil. However, if the pesticide deposit takes place where underlying limestone bedrock or rolling, sinkhole topography can speed drainage, pollutants have a minimized chance of being attenuated.

Residues of DDT, 2, 4-D, lindane, and herbicides form the focal point of ground water contamination discussion and research. In documenting pesticide and herbicide application effects, arsenate compounds used in insect control in Maine's blueberry fields have been detected in shallow ground waters. Chlorinated hydrocarbons used on Massachusetts cranberry bogs were reported in a sand and gravel well. Examination of soil samplings in the Houston black clay of three watersheds in Waco, Texas demonstrated that DDT was not absorbed by the clay and had percolated down into the ground water.

RECENT RESEARCH FINDINGS ON GROUND WATER CONDITIONS AND AGRICULTURAL TECHNOLOGIES

Depletion - M. Feldman,[14] et. al., (1976) in "Economic Analysis of Alternative Ground Water Withdrawal Rates in Conjunction with Surface Irrigation" compares the economic elements of adopting a policy to avoid a 10 foot per year decline in the static water level versus policies tolerating more considerable drops in ground water levels as the result of irrigation pumping. Using a variety of computer models, conclusions showed that if water levels are stable, water can be economically pumped from great depths. Findings show that as the static water level declines, the absolute depth at which water can be economically pumped is limited.

R.G. Borman and T.G. Major[15] (1977) in "Water Level Changes in the Northern High Plains of Colorado, 1964 to 1976" (USGS) report water levels in the Ogallala Formation have been consistently declining in regions experiencing ground water pumping for irrigation. Declines of 32 to 40 feet have been monitored in Kit Carson County from 1964 to 1972. In other areas influenced by irrigation, declines of less than 16 feet have been noted between 1964 and 1972 and less than eight feet from 1972 to 1976. USGS findings confirmed a more rapid water level decline in the Ogallala Formation since 1974. More than 98 percent of the Ogallala pumpage originates with irrigation agriculture. The aquifer is recharged by precipitation at an annual rate of less than a quarter-inch each year.

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Fertilizer - Caldwell and Buzicky[20] (1979) in "Water Quality of Aquifers as Affected by Movement of Fertilizer Nutrients Under Irrigation," analyzed the effects of both the amounts and timing of nitrogen fertilizer in research reported to the Water Resources Center. Movement of nitrogen into the aquifer 4.5 miles below the surface was detected. Field experiment took place with split applications throughout the growing season in Central Minnesota.

N.K. Patni[21] (1978) in "Physical Quality and Sediment Transport in Drainage Water From a Manured and Fertilized Cropping Operation" investigated sediment transport of large-scale plowdown of liquid manure into cropland. Findings showed that immediate plowdown, manure application during dry periods, application away from streams and rotation of field subject to manure application significantly reduced effects on drainage water quality.

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Pesticide/Herbicide - T.L. Wu,[23] et. al., (1977) in "Runoff Studies of the Agricultural Herbicides Alachlor and Atrazine From the Rhode River Watershed During the 1976 Growing Season" monitored herbicide concentrations in the soil profile and runoff waters. Residual atrazine was measured in the deeper soil profile (24-30 cm) 148 days after field application. Detectable levels of alachlor were greatly reduced 15 days after application. Substantial transport of atrazine and alachlor in the dissolved phase of water runoff was indicated. In the study of cornfield runoff, atrazine loss was gauged at 1.2% and alachlor .02%.

K.S. Lafleur,[24] et. al., (1973) in "Movement of Toxaphene and Fluometuron Through Soils to Underlying Ground Water" summarize findings of field research in which toxaphene and fluometuron were applied to the topsoil and observed for a one-year period. Both compounds were found in underlying ground water two months after application. Residues persisted throughout the one-year observation period.

4. ADEQUACY AND COMPATIBILITY OF GROUND WATER DATA

GROUND WATER DATA AND THE SOIL ENVIRONMENT

In Iowa, two bushels of soil are lost for every bushel of corn grown, according to Iowa agronomists. Throughout the nation, U.S. farms are losing ground at the rate of nine tons per acre.[25] To study the mechanics of erosion and the interplay of the hydrological cycle, data is needed specifically on detachment and transport by runoff. The direction and rates of ground water flow and the extent of water level declines are critical to a comprehensive understanding of its impact on the soil environment.

The variety of ground water data required to analyze the soil environment and solve soil environment problems needs to be site specific to productively deal with the hydrologic conditions of the aquifer and soil science. For generalized planning and development, the USGS series of Professional Papers 813 can be suitable for summarizing the recent data collections and understanding of regional ground water, but it doesn't help the farmer in Houston County Minnesota whose top soil is washed down to the subsoil.

To estimate field soil loss data that farmer has to know extremely localized features of soil properties, topographical oddities, and hydrologic elements. What data is available to show the extent and borders of aquifers and non-water bearing strata in Houston County? Is there accessible information on water table bedrock configuration and saturated thickness for southeastern Minnesota? Is there an inventory of the extent of recharge areas -- irrigated areas, recharge wells, and recharge basins in the county? How many USGS ground water stations monitor ground water levels in Houston County? What is the frequency of pumpage data collection?

If we rely on the Catalog of Information on Water Data - Region 07 to provide information on ground water quality in Houston County, we will be disappointed. There are none, according to the publication. Because water moving through the soil surface and into the subsoil represents one segment of the hydrologic cycle, more localized data on the interactions between ground water and soil environments must be expanded if we realistically expect to deal effectively with approaching problems in the soil sciences.

GROUND WATER DATA AND VEGETATION

In considering ground water data availability and effects on vegetation, we are essentially concerned with the topic of changes in ground water levels and flow. If ground water rises to the top soil or just below it, there is a problem known as waterlogging, in which vegetation growth is impaired because plant roots are deprived of air supply. If the water level is a few feet below the surface, capillary action and heat produce the condition of salinity mentioned earlier.

Principal data requirements for an analysis of optimum conditions for vegetation would have to answer: Can a continuous, long-term production of ground water pumpage for irrigation be available? Will the data forecast potential discharge areas -- areas where ground water in an unsaturated zone is discharged on the land surface? What is the areal distribution of water quality in the aquifer? Will water levels be sufficiently current to predict the necessity of artificial recharge or the importing of water?

Will data assess the aquifer storage and borders and enable determination of progressive storage depletion?

Questions on ground water levels are easy to ask, but less easy to discover are the data to answer them. There are 58 USGS ground water stations in Minnesota monitoring ground water levels, according to the U.S. Department of the Interior, or approximately one ground water monitoring station for every three counties. Although this is not a representative example of the distribution of ground water monitoring sites, it is a clear, common sense illustration of the potential vastness of the ground water data base and an indication that we are only scratching the surface. Since we clearly realize the importance of managing surface water's relation with vegetation for conditions of imbalance (floods, droughts), it would seem that we can just as readily realize the viability of more site-specific ground water monitoring to avoid ground water deficiency or excess.

GROUND WATER DATA AND AQUIFER ENVIRONMENT

For water planners and managers, surveying the relationship of ground water data and the aquifer environment is an important factor in organized ground water resource planning. The collection and processing of ground water data can assist in day to day aquifer management, in a predictive function of ground water problems, in a prescriptive role of assisting with alternatives, and in a public relations capacity of providing hard evidence to persuade the general public of the adoption of new ground water policies.

The types of data needed for aquifer management include the interaction between the aquifer and streams, the relation of saturated thickness to transmissivity (the rate at which water of a prevailing kinematic viscosity is transferred through a unit width of an aquifer under a unit hydraulic gradient), the fluctuations in storage coefficient (the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head), the amounts and types of recharge and discharge, the record of pumping rates and pumping distribution, the water level gain and loss measurements, a history of water supply and demand, the hydraulic and geochemical relations of aquifer and surrounding geology, and the borders of non-water bearing rock and aquifer.

By the Geological Survey's own admission, current information is still not sufficient for applying hydrologic principles toward understanding local water occurrence. As the source of more than half of the nation's water data base, the USGS advises that a major push in ground water research and investigation will have to occur before the aquifer environment realizes its complete operational role in the nation's water planning and development.

GROUND WATER DATA: CONSTRAINTS OF TIME SERIES ANALYSIS AND REGIONAL ANALYSIS

To fully understand the constraints of time series and regional analysis on ground water data collection, it is axiomatic that not only are no two aquifers alike but not even one aquifer is homogeneous within itself in terms of numerous hydrologic factors and ground water system behaviors.

Analyses of ground water environments are complicated by the fact that the measured environment, unlike surface waters, is an unseen one. In addition, there are a diversity of ground water basins, climates, types of aquifers, geologic structures, numbers of aquifers, rates of discharge and recharge, storage capabiility, etc. which invite disaster for anyone with ideas of uniform quantification. It is these localized features with their infinite permutations that make ground water data collection such a difficult and time consuming venture.

Ground Water Basins and Types of Aquifers - One of the key features of basins is the type of surrounding waterbearing rocks. Its lateral and vertical changes, the thickness and lateral extent, the varying layer of strata, the content and shape of underlying and overlying impermeable rock, and the content of the ground surface serve as a mix of conditions for influencing variations in regional ground water data collection.

For example, within the same area an intermingling of permeable and impermeable rock could cause different aquifers to be stacked one upon another at various depths. Although monitoring wells could be drilled just a few dozen feet from each other, if each penetrated a different aquifer at progressively lower depths, the water levels in each well would be different and indicative of the aquifer drilled.

Geologic Structure and Climate - Although ground water can be found in both consolidated rock and in loose, unconsolidated rock, an aquifer requires a porous, permeable rock which will not inhibit movement. The depth of an aquifer, their numbers, their outcrop patterns, and their interconnections are all determined by geologic configurations, structures, and history.

Constraints on time series data collection can easily be recognized with the appropriate alliance of geologic conditions and climate. If an aquifer formation in a sand and gravel strata with a naturally recharged outcrop area is monitored for water levels in the spring, the measurements might appear uncharacteristically high after winter runoff. After a long, dry summer a second measurement would differ significantly.

Seasonal patterns in precipitation, evapotranspiration, and discharge from wells produce seasonal fluctuations in ground water levels which complicate data collection for time series analysis. These changes are a response to water movement into and out of the aquifer. In many locations, water table recession occurs in summer and early fall when discharge by runoff to streams exceeds the corresponding recharge from rainfall. Aquifer water levels also experience longer periods of vacillation involving numbers of years. Such water levels can be indicative of a series of dry and wet years in which natural recharge fails to catch up to the mean or lags far behind it.

Agricultural use imposes unique time series constraints on the analysis of water levels. Throughout the growing season, the water table changes in response to evapotranspiration loss. As evaporation from the soil and water needs of the vegetation are satisfied, there is a corresponding ground water loss. As evapotranspiration losses occur during sunlight hours and peak with the midday sun, an accompanying increase in drawdown can be detected, rising in the morning and falling about 6 P.M. After sunfall, a decrease in the rate of drawdown takes effect as a restorative process.

The response to atmospheric pressure changes must also be taken into account for time series analysis of artesian wells. To a small degree, however, levels in artesian wells will be patterned by pressure changes, receding as atmospheric pressure increases and rising as pressure decreases. Maximum barometric pressure is reached at approximately 10 A.M. and 10 P.M., while minimums are measured at 4 A.M. and 4 P.M.

For a realistic analysis, the ground water environment can hardly be considered from an isolated perspective. For example, the geological sensitivity to the pressures caused by a passing train can intrude upon an accurate gauging of artesian water levels. As the train increases hydrostatic pressure, a rapid rise in water level occurs with the train's approach. A slow recovery begins a few minutes after its passage.

Aquifer Boundaries - A similar overview must be adopted for any analysis understanding the interplay of influential factors introduced in the aquifer's boundary conditions. We can expect very different circumstances in the presence of an impervious, semipervious, and river/lake boundaries.

Water exchange through an impervious, clay layer could be predictably negligible for offsetting analysis. A similar flow through a semipervious, alluvial boundary could be similarly disregarded as being assumed to be fairly constant. However, when an aquifer is wholly or partially bounded by a body of water, tidal, reservoir, or river, level fluctuations must be taken into account.

Thus, in coastal or lake abundant regions, an aquifer is more susceptible to the loading effect of foreign influences. Water levels in ocean bordering wells would be influenced by the same diurnal ebb and flow of the tides, although not to the same extent. Water vacillation resulting from tidal activity is measurable but small.

CONSTRAINTS IN THE INTEGRATION OF GROUND WATER AND CROPLAND DATA BASES IN PREDICTING PRODUCTIVITY

It has by now been documented that agriculture and ground water resources are symbiotically aligned, since at various points in the hydrologic cycle an actual physical intermingling occurs between the two environments. But, at times, their data bases seem at cross-purposes.

The difficulty that arises when integrating ground water and cropland data bases in the prediction of future agricultural productivity is dealing with a multiplicity of uncontrolled unknowns both in the ground water field and in agriculture.

The urban encroachment on U.S. croplands is growing at a phenomenal rate. In the eight years between 1967 and 1975, 2.5 million hectares of abundant cropland were converted to urban sprawl. And this urban bite is expected to increase in the next two decades, leaving U.S. agriculture holding the bag -with the task to feed more and more people with less and less land.

It becomes self-evident when confronted with this dilemma that we will have to prepare to maximize our agricultural management and, in particular, our irrigation efficiency. In this area, we come across data deficiencies in projecting the effects of the much discussed, much researched topic of salinized soils. The U.S. farmer currently doesn't have a data base at his fingertips which inventories the distribution and extent of soils influenced by salinity. He doesn't know what soils have experienced limited and extensive salinity damage. In this vacuum of soil salinity monitoring, how can we expect the U.S. farmer to exercise informed irrigation management?

Another unknown, in the agricultural equation toward forecasting productivity, is the organization of the off-farm irrigation distribution system itself. Delivery of water through a canal system is on a fixed schedule for large irrigation projects. The farmer using this system is at the mercy of a delivery schedule, controlling neither amounts of irrigation water received nor deadlines for receipt.

A constraint to more efficient ground water management in irrigation use is the scarcity of site specific information on the capacity of aquifers which hold an estimated total of 200 billion acre-feet of U.S. ground water. If the ground water data base could provide response times for specific aquifers throughout the nation, the aquifer system could be exploited as a depository for excess surface runoff. By drawing the water table down within an aquifer, storage areas would be available for water during flooding seasons. The farmer, who can probably tell you the storage capacity of his silo, can probably not even guess at the limits of his aquifer storage for one of his most important resources -irrigation water.

Expansion of the data base on ground water degradation will be required if we expect to adequately answer questions of increased productivity. Again, localized information is the focus of our criticism. To illustrate the inapplicability of the use of many generalized research findings to solve one farmer's ground water problem, consider the agricultural residues nitrogen and phosphorus. A farmer would know that a combination of animal wastes, fertilizer, and crop residue runoff introduce nitrogen and phosphorus into the soil. What are the percentages of residue lost in the ground water? What local soil properties enhance or decrease the runoff rate? What role do fertilizer application rates play in determining runoff percentages? Does the amount and intensity of precipitation figure into runoff predictions? When a consideration of the complexity of local variables is initiated, the data is just not available to provide practical answers on ground water degradation.

For solving problems in areas with peculiar and complex hydrologic and geologic elements, mathematical models of ground water basins and aquifers offer the best feasible options for a site-by-site examination of factors but would be too time-consuming and costly.

GROUND WATER MODELS SHOULD BE USEFUL TOOLS FOR TOMORROW

There is a significant lack of understanding among the majority of individuals about mathematical models. I have asked many learned people for a succinct definition, but they are unable to deal in basic terms understandable to laymen.

A mathematical model is, in fact, simply a numerical representation of a physical system. No more, no less. Models act to represent some portion of the real world by numbers or symbols that may be manipulated to facilitate their study. Models will do exactly what we instruct them to do, but not necessarily what we want them to do. Computers, though they facilitate simulation, are not necessary for this task. Modeling does not require the use of a complex computer system.

Though it may differ substantially in form from the object or situation it represents, a model always simplifies what it portrays. We lose sight of the simplicity of mathematical models in our effort to be sophisticated in dealing with complex problems.

There are two major problems with all ground-water modeling. First, the models are out of touch with reality. Second, our ability or desire to relay what the models mean is too fouled up in jargon and general obfuscation.

The second problem with models deals with our lack of ability or willingness to translate what we know into terms that others can understand. We have not lost the art and skill of verbal articulation, but we are afraid to use it. Obscure prose by those who should know better has become the rule rather than the exception.

We all try to make things complicated, but if we are to succeed in making ground-water models accepted and useful, we must back up and tell our peers how models work and how to develop them. If you are a talented hydrogeologist who graduated before 1970, you are probably not a modeling expert. Unless you have been channeled into modeling because you are with USGS or are with some other agency or research group that uses modeling, you are likely to be one of hundreds of intelligent people who do not understand mathematical models.

Many people need a better understanding of what models can do so they can know when to ask for help in understanding how to develop a model that will be sensitive to their particular problem. We need to educate many different people. We need to make more hydrogeologists capable of modeling and educate the ground water resource managers who use the models so they will know what is available to them.

PRACTICAL METHODS USED TO PREDICT CONSEQUENCES OF TECHNOLOGICAL IMPACT ON GROUND WATER RESOURCES

Well Log Records - Electric logging, spontaneous potential logs, radiation logs, temperature logs, caliper logs and fluid-conductivity logs are all useful methods of subsurface exploration. The impact of technologies can be determined through the various data yields on aquifer structure, depth, continuity, thickness, porosity, permeability, saturation, water temperature, areal extent, and water quality through well logging. In well logging, the typical properties of each strata level are recorded.

Electrical logging uses a record of the resistivities, generated by the subsurface formations, hand in hand with the spontaneous potentials (or the depth of the electric potential in millivolts recorded in the borehole. Each is recorded on a graph. As water is a natural electric conductor, its occurrence in the formation lessens resistivity. The extent to which resistivity decreases is related to water mineralization. Thus, because salt water, as a good conductor, would yield low resistivity, high levels of salinization would be discerned in electric logging.

To identify the strata location of mineralized water and its internal flow, spontaneous potential logging is relied upon. This method employs a galvameter linked to a ground surface terminal and a traveling electrode on a conductor within the borehole. By measuring the difference between the earth's surface and the location of the electrode in the borehole, a log is eventually produced in which deflections portray potential differences between points at varying depths in the well.

When information about subsurface bed configuration, bed lithography, or the extent of aquifer boundaries is needed, radiation logs are utilized. The primary tools for measurement in radiation logging are a Beiger-Muller counter, a scintillation counter, and a neutron detector. A diversity in intensity of natural radioactive emission, by various rocks, enables the differentiation of strata when combined with a knowledge of the local subsurface geology. The radioactive log can also calculate the aquifer dimensions by determining the tops and bottoms of surrounding aquifer bedrock. With the interpretive capacity of radiation logging, the fluid content of the rock can be known in more detail.

Temperature logs are used to distinguish the well tapping of one or more aquifers. If a condition of ground water degredation has occurred in one aquifer but is not present in the second, the water temperature differential can be used to differentiate between the two.

For a generalized idea of ground water quality, a fluid-conductivity log provides data on the depth of salt-water leaks and the depth of artesian head (the height above a standard datum of the surface of a column of water that can be supported by the static pressure at a given point) of salt water aquifers. Two closely spaced electrodes are lowered into the well, connected to two-conductor insulated cables which are joined to a battery or generator on the surface. Fluid conductance at various depths is measured and plotted on a graph along with depth of measurement. When a gradient is displayed, it is an indication of conductivity variance. This variance, and a knowledge of local hydrologic conditions, permits an interpretation of water quality.

Hydrogeologic Maps - When a summary of the area geology, water levels, and rates of recharge and discharge for ground water resources are needed, the hydrogeologic map becomes a fund of information.

Water levels are mapped according to a range of different variables shown in water-level-contour maps, water-level-change maps, depth-to-water maps, water-level profiles, and hydrographs. Water-level-contour maps are further categorized according to water-table maps and piezometric-surface maps. The piezometric surface is an imaginary surface depicting the artesian pressure in all or part of an artesian aquifer. Ground water flow is also indicated on the water-level-contour map.

During given measurement time span, the change of water levels of different monitoring wells is recorded. This data is portrayed on water-level change maps.

For water-level overviews, differences in water levels at various depths are shown on depth-to-water maps. Hydraulic gradients combined with the vertical movement of ground water are also pictured.

Finally, in long-term and short-term water-level hydrographs, there is a presentation of rates of aquifer discharge and recharge. Fluctuations in aquifer storage are recorded here.

5. CONSEQUENCES OF GROUND WATER DATA INADEQUACIES

MISUNDERSTANDING GROUND WATER RESOURCES IN CROPLANDS - EFFECTS ON GOVERNMENT POLICY

In fiscal year 1980, EPA's Water Quality Management Program will spend between $10 and $20 million on planning and implementation of ground water quality protection projects. However, an understanding of the preservation of our nation's largest fresh water source in terms of storage volume, ground water, and its relation to agricultural practices, is still in its infancy. Ground water pollution didn't capture headlines a decade or more ago when surface water contamination was the focus of concern. Ground water pollution is still a new topic.

To date, the EPA's Water Quality Management (WQM) Program is the only comprehensive Federal effort undertaken to address the issue of ground water quality protection. WQM has the responsibility to study a complete ground water problem. Coordinating data from other Federal programs, it directs and organizes controls from the appropriate authorities.

Those ground water controls are splintered through a number of programs. Underground Injection Control is affiliated with the Drinking Water program in which sole source aquifers, ponds, and lagoons are regulated. The Solid Waste Program manages the disposal of hazardous wastes, open dumps, and landfills -- sources of frequent nonpoint ground water pollution.

Prohibition of aquifer contamination is part of Federal legislation in the Resource Correction and Recovery Act (RCRA), the National Pollution Discharge Elimination System (NPDES), and the Safe Drinking Water Act (SDWA). Kansas and Connecticut have legislation under consideration which would implement ground water controls. The Water Policy Reform Message highlighted five programs designed to address specific water resource management problems which Federal agencies will be required to study. Ground water was listed among the five programs.

Despite this welcomed flurry of Federal and state recognition of ground water problems, the legislative lag time can be attributed to some strong prevailing ground water mythology: one, that ground water and surface water are mutually exclusive entities that can be managed exclusively and regulated exclusively; and two, that ground water moves in mysterious, unmeasurable, and unpredictable ways.

The isolation of ground water and surface water considerations results in an administrative mismanagement of both resources. It's the failure to perceive these two elements as part of the same hydrologic cycle that prompts their inappropriate consideration as separate entities in issues such as irrigation. This insular treatment extends in most cases to the laws pertaining to their use, to the federal agencies and institutions which regulate and control them, and to the research and development which guides their future uses.

Much of the misinterpretation surrounding ground water finds its source in a misunderstanding of the ground water behavior in aquifer systems. It can be safely stated without qualification that the ground water data base is substantially smaller than the surface water data base. For aquifers with rapidly declining water levels, there are pressing questions which current ground water data can't always answer:

- aquifer extent, transmissivity, and saturation
- local feature potential for artificial recharge programs
- storage capacity within aquifer
- water quality and pollutant origins
- history of ground mining
- sustained yield of aquifer

When we have a data base which can address the preceding points, it will introduce a more informed, realistic assessment and more effective ground water planning and management.

MISUNDERSTANDING GROUND WATER RESOURCES IN CROPLANDS - AGGREGATE ECONOMIC AND SOCIAL EFFECTS

To ignore a substantial hydrologic imbalance costs money -- money in production costs, farm income, crop prices, food prices, and land values. For cropland affected by ground water problems of depletion, salinity, and subsidence, a total calculation of ground water related damage has not been compiled. However, when specific sites are discussed, the figure is well over the multimillion dollar mark.

The price tag for one year's worth of salinization for the entire length of the Colorado River is $53 million in crop yield loss and increased corrosion. If salt pollution were to be lessened to acceptable levels, the Soil Conservation Service reports that it would take a hefty

$3.2 billion to do it. Another $1.8 billion would be needed in the pesticide and fertilizer pollution clean up. Add another half billion to bring animal waste pollution to acceptable levels, and the resulting tab for agricultural pollution is an impressive one. Subsidence related costs also don't budge from the multimillion dollar category. In Santa Clara Valley, subsidence costs are estimated to be $15 to $20 million.

Directly entwined with the ground water economic impact is the ripple effect felt by society. As ground water problems increase in severity, interactions between producers directly affected and those not affected can be expected to create new meanings for land values and production relocation. For example, as salinization increases for farm land along the Colorado River, after $53 million worth of salinity damage costs are considered,the producer's net income drops because of crop devaluation and increased production costs. However, the lands of a producer with the same crop in an area without salinity impact would expect the lands to increase in agricultural value.

Eventually, this imbalance will spur production relocation and a consistent pattern of passing increased costs on to food consumers. The rural business community of banks and agricultural suppliers are ultimately influenced through alteration in service demands and tax base. And, if the irrigated dry western states are compelled to revert back to dry farming as salinity takes its toll, the ultimate effects on consumer food prices and the entire economy would hardly be minimal.

To assess the social implications of mismanaged ground water requires a more extensive survey of variables and analytic methods than can briefly be considered here. Such questions, involving basic policy, warrant more vigorous study by Federal and State agencies participating in the ground water decision making framework.

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